STUDY OF AN ANIMAL RESEARCH FACILITY (USING S-IVB) FOR A MANNED ORBITAL BIOTECHNOLOGY LABORATORY

FINAL REPORT

DOUGLAS
MISSILE & SPACE SYSTEMS DIVISION

SEPTEMBER 1967

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PREFACE

The Douglas Aircraft Company is conducting a feasibility study of a Biotechnology Laboratory for manned orbiting missions under Contract No. NAS7-518, sponsored by the Office of Advanced Research and Technology of the National Aeronautics and Space Administration. The contract to date has called for a study of the requirements of a manned orbital animal research facility. By a recent contract amendment, the study will now include the requirements of a Biotechnology Laboratory which will provide facilities for the performance of experiment programs in the areas of biomedicine and applied animal research, bioscience, behavior, EVA, and life support systems. The work completed to date has been designated as Phase I of the amended contract; the ensuing effort as Phase II.

Work on this study is being performed as a joint effort by personnel from two departments of Advance Systems and Technology at the Douglas Aircraft Company: Advance Biotechnology and Power Systems, Dr. K. H. Houghton, Chief Engineer; and Advance Space Stations and Planetary Systems, Mr. T. J. Gordon, Director.

In consideration of the animals recommended as experiment subjects in this report all care and handling techniques, and experiment procedures, will be in accordance with the "Principles of Laboratory Animal Care: established by the National Society for Medical Research.

The Phase I portion of the study, in which experiments in applied animal research, and their support requirements have been defined, has been completed and the final results are

described in this report. Since the revised subject of the study was defined after the completion of the technical effort on the Phase I portion, the material in this Animal Research Facility report was developed without regard to the integrated Biotechnology Laboratory to be studied in Phase II.

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Section 1
INTRODUCTION

1.1 STUDY BACKGROUND

The manned orbital animal research facility study was undertaken in September 1966, under contract with NASA (OART) to examine the feasibility of conducting a meaningful program of animal experiments in various configurations of the orbiting Saturn S-IVB workshop, including the prelaunch modified S-IVB space station version of EOSS.

The role to be played by biotechnology in the attainment of national space goals has been described in the recently published PSAC report. (Reference 1.)

Biological research is identified in Reference 1 as contributing to two of the five space objectives for the next decade: No. 3, long-term flight and No. 5, advancement of science. These two objectives may be related to Paragraphs 2 and 3 and Paragraphs 1 and 4, respectively, of Section 102 (c) of the NASA Space Act of 1958.

The need for experiments involving animals is identified in the above-mentioned document. The President's Science Advisory Committee (Reference 1) in their discussion of the "Available and needed biomedical information," states:

> "A wide gamut of fundamental information in basic biology and mammalian physiology should be acquired concurrently with observations on man. Studies in cellular biology will provide unique information on the effects of prolonged exposure in space in simple living systems. Observations in animals can be anticipated to provide more detailed and comprehensive information on central nervous, cardiovascular, and metabolic functions than would be feasible from studies in man. --------."

They recommend,

> "NASA should proceed vigorously with basic bioscience programs in biosatellites and in prolonged manned flights

with vehicles suited to care of animals and simple living forms. In addition to its fundamental value, this information could be important to our understanding and solution of problems of manned flight."

1.2 STUDY GOALS

The first goal of the study was to determine the extent to which various configurations of the Saturn S-IVB workshop could meet the support requirements of a laboratory facility in which animal experiments could be conducted.

The second goal was to identify the supporting research and technology (SRT) items which would require attention before the facility could be mechanized.

Finally, recommendations concerning the implementation of the animal research facility program were to be prepared.

1.3 STUDY APPROACH

The approach taken to achieve the above goals is outlined in the statement of work for the study (Appendix to this report).

It is important that the reader clearly understand the purpose of the experiment programs prepared and used in this study. Although they are based on a thorough consideration and definition of essential areas of investigation, they are merely representative programs which permit the identification of support requirements and "configuration drivers." The suitability and realism of the programs for this purpose was agreed upon at the presentation to NASA of the "20% Effort Progress Report."

In many studies of the effects of space flight, weightlessness has been considered as a physical stress. In this report, however, it is preferred that the weightless state be viewed as the absence of stress, and that a 1-g environment constitutes a positive stress.

The following hypotheses were used:

1. Adaptation of the living organism to a new level of stress will proceed to equilibrium or endpoint.

2. The time to reach equilibrium is different for each body tissue or subsystem.
3. The time to reach the end-point is dependent upon the rate of change in the response of that subsystem and the magnitude of the steady-state stress.

The extent of adaptation will be evidenced by the rate of change of the parameter being observed. Adaptation will be complete (that is, the end-point reached) when the rate of change approaches or is equal to zero. There is very little information concerning the time required for this process in the weightless environment. Some relevant data are available from bed-rest studies. It is predicted that the time required for some subsystems to reach equilibrium will be in excess of 40 days.

It should be pointed out further that the experiment programs are made up of "areas of interest" and not "detailed" experiments. This approach is based on the fact that if a facility is provided which permits measurements and observations in an area of interest, numerous experiments may be designed which take advantage of that facility.

The initial study of experiment programs was based on animal experiments which could be related to man in the space environment, that is, mission-oriented experiments. The programs were extended to include bioscience or experiments not man-oriented by Contract Modification No. 2.

Since information concerning the necessity for sharing the workshop systems was lacking, it was possible to indulge in the luxury of consuming as many of the available resources as necessary to achieve the configurations of the research facility and to mechanize the individual programs. This approach provides a yardstick of experiment program versus requirements. More recent information, however, indicates the necessity for shared resources. The impact of this requirement on the individual programs is discussed.

Supporting research and technology (SRT) items were identified throughout the study, but in the interest of planning, they are presented in a single portion (Section 6) of this report. Although SRT items may, by their nature, be classed as "long-lead-time items," those which fit this latter classification are not included in this section.

1.4 STUDY RESULTS

The detailed results of the study are described in succeeding sections of this report. A summary of the results, major problem areas, and recommendations is presented in this section.

In consideration of the requirements of the man-in-space program, it was determined that the acquistion of information about the effect of weightlessness on the physiological subsystems of man should take precedence over any other animal research effort. The course of injury and disease was considered next in importance since, although they may occur, a conscientious effort would be made to avoid these medical problems during space operations. The use of animals for research in these areas is an accepted method of obtaining relevant data which, by competent analysis, may be used to forecast man's reaction to similar conditions.

Standard laboratory animals were studied to select those most suitable as research subjects in each specific area of investigation. Representative animal experiment programs for both short-term (30 day) and long-term (greater than 90 days) missions were prepared.

The short-term program will provide injury-healing data and some deconditioning data, but will require the return to Earth of the sacrificed subjects, since on-board analysis of experiment results will not be possible. The long-term program will provide for a wide range of deconditioning experiments and course and treatment of injury and disease experiments. It will rely heavily on the on-board analysis of experiment measurements.

The currently conceived configurations of the Saturn S-IVB, either as a spent-stage workshop or as a ground-equipped space laboratory, can provide the resources necessary for an animal research facility. In spent stage workshop missions, the experiment program scope is constrained by the mission duration, the payload and resources available, and the crew tasks required to set up and operate the facility. In ground-equipped space laboratory missions, the experiment program studied is constrained only by the availability of measurement and procedure techniques for a zero-g laboratory and the crew time available for the experiment tasks.

Throughout the study, many items were identified which will require development before an operational laboratory is achieved. These SRT items are discussed in Section 6. Animal housing and environmental control and life support (EC/LS) systems, suitable for use in a manned space station, were felt to be among those items needing earliest attention. An early experiment to test a design concept of these systems is described in Section 7. Another critical SRT item is the development of equipment to perform measurements which are currently made with equipment which is gravity dependent. Fluid-handling techniques in zero g, while not peculiar to animal programs, will require development for a variety of observations and measurements.

In consideration of the magnitude of development which must take place before an animal laboratory becomes an operational reality, it is recommended that as much SRT as possible be conducted in the spent-stage workshop type missions, leading to an operational laboratory in a ground-equipped space station. Because animals will no doubt be required in the flight evaluation of equipment and techniques, an opportunity will exist to conduct experiments in conjunction with these SRT efforts. Such experiments should be planned to provide preliminary information for the extensive experiment programs of an operational station. In this context, in-flight experiments which validate Earth-based simulation techniques will increase the effectiveness of the orbital research facility by removing needless experiments.

The space station development programs outlined in Section 8 indicate the need for an early start on the animal research facility development effort. Experiment program definition is an essential part of the effort.

Section 2
EXPERIMENT PROJECT

To study the capabilities of the Saturn S-IVB to support a manned orbital animal research facility, it was first necessary to describe the research which would be performed. Because a coordinated research program was not available for this purpose, NASA directed that the first task of the study would be the definition of such a program based on the contractor's knowledge and understanding of requirements for information. This program was not to be limited to the scope of experiments already planned, but was to take an unrestrained approach to the problem. Accordingly, a representative experimental program was defined and approved by NASA for use in this study.

Section 2.1.2 presents an inclusive experiment matrix of the information requirements for a manned space program. The selected experimental program will progress sequentially; information gained from any specific experiment can affect the structure and content of the subsequent experimental program. Experiments are identified for system configurations and are detailed to that level necessary for sizing laboratory subsystems. Only example experimental programs for each configuration are provided, with identification of the animals that would load the environmental control system, the measurements to be taken on these animals, and the equipment required to accomplish the experimental program.

2.1 EXPERIMENT LIST

2.1.1 Literature Search

The Douglas Aircraft Company was directed to use a new approach in the determination of experimental programs for the animal laboratory; therefore, a literature search was not required. A comprehensive evaluation of completed and scheduled biomedical experiments was not necessary to size laboratory subsystems, but a formal analysis will be required before the design definition phase.

2.1.2 Experiment Selection

Experiments used in this study have been selected from an inclusive experiment matrix. Table 2-1 presents most of the factors affecting the survival of man in an orbital environment. This matrix is composed of a vertical list of physiological measurements and a horizontal list of stresses. Each cell in the matrix formed by the intersection of a physiological measurement and a stress is a potential experiment.

Generally, those stresses such as physiological degradations resulting from zero g, that occur on all flights and are serious enough to require immediate attention, will be given top priority. Medical healing experiments are also of high priority because this kind of information would be required in the event of accidents in orbit.

The following criteria were used to select individual experiments from the matrix of experiments:

1. Primary Criteria.
   - A. The value of the data in planning for operational manned flights of 1 year or more.
   - B. The technical knowledge regarding effects of long-term space environmental factors (for example, zero g, radiation, and dietary requirements) expected to be available by the time a mission is performed.
   - C. The value of the data for experiment modification and planning for future experiments.
   - D. The leading anticipated zero-g physiological degradation problems, and anticipated preventive or therapeutic approaches to their resolution.
   - E. The leading anticipated medical problems and approaches to their resolution.
   - F. Flight-qualified experiment equipment available by the time a mission is performed.
2. Secondary Criteria.
   - A. Weight, volume, and power requirements of the experimental apparatus.
   - B. Requirements for new and specialized techniques for data acquisition as a function of constraints imposed by physical parameters of the flight.
   - C. Crew skill and training requirements.

Table 2-1 (Page 1 of 2)

MATRIX OF EXPERIMENTS

Physiological Subsystems and Measurements of Their Status	Environmental Stresses*																		
							Traumatic Tissue Damage												
	Radiation	Psychological Stress	Vibration	Noise	Infection	Particulate Matter Inhalation	Puncture	Toxic Inhalation	Fracture	Crushing Wound	Contusion	Abrasion	Cut	Chemical Burn	Thermal Burn	Cabin Temperature	Explosive Decompression	Atmospheric Composition	Atmospheric Pressure Level
Cardiovascular																			
Heart weight and histopathological examination																			
Heart rate																			
Blood volume and plasma volume																			
Red blood cell mass																			
Blood composition																			
Blood pressure																			
Vasomotor control																			
Thoracic blood flow																			
Cardiovascular work capacity																			
Venous compliance																			
Hemostasis																			
Hematological defense																			

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Hemoglobin																				
Chromosome studies																				
Respiratory																				
Lung weight and histopathological examination																				
Respiration rate																				
Vital capacity																				
Pulmonary function																				
Ventilatory gas exchange																				
Gastrointestinal																				
Stomach weight and histopathological examination																				
Small-intestine weight and histopathological examination																				
Large-intestine weight and histopathological examination																				
Food intake-waste output																				
Gastrointestinal motility																				
Gastrointestinal pH																				
Skeletal																				
Skeletal weight and histopathological examination																				
Bone demineralization																				
Calcium balance																				
Muscular																				
Muscle-mass weight and histopathological examination																				
Muscle strength																				
Urogenital																				
Diuresis																				
Gene changes (sperm and ova)																				
Urinary tract function																				

*These stresses should be provided under different artificial gravity levels and different exercise levels.

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Table 2-1 (Page 2 of 2)

Physiological Subsystems and Measurements of Their Status	Environmental Stresses*																		
							Traumatic Tissue Damage												
	Radiation	Psychological Stress	Vibration	Noise	Infection	Particulate Matter Inhalation	Puncture	Toxic Inhalation	Fracture	Crushing Wound	Contusion	Abrasion	Cut	Chemical Burn	Thermal Burn	Cabin Temperature	Explosive Decompression	Atmospheric Composition	Atmospheric Pressure Level
Urogenital (Continued)																			
Renal function																			
Gonad-weight and histopathological examination																			
Kidney weight and histopathological examination																			
Endocrine																			
Endocrine-gland weight and histopathological examination																			
Endocrine-gland function																			
Endocrine balance																			
Temperature Regulation																			
Temperature measurement																			
Temperature correlation with endocrine																			
Temperature correlation with cardiovascular																			
Skin																			

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Skin function																			
Immunologic																			
Immunologic function																			
Sensory Perceptual Processes																			
In-flight sleep analysis																			
Vigilance/attention																			
Memory																			
Problem solving																			
Psychomotor function																			
Adaptability																			
Emotional reactivity																			
Vision																			
Audition																			
Kinesthetic																			
Otolith																			
Semicircular canals																			
Olfaction																			
Gustation																			
Touch sensation																			
Pain sensation																			
Heat-cold sensation																			
Neurological reaction time																			
CNS studies--sensory deafferentation																			
Homeostasis																			
Metabolic rate																			
Body mass and general examination																			
Traumatic shock resistance																			
Radiation resistance																			
Total body water																			

*These stresses should be provided under different artificial gravity levels and different exercise levels.

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D. Time required to perform the experiment.

E. Number of crew members required to perform the experiment.

The foregoing criteria were applied to all the potential experiments in Table 2-1. This analysis resulted in the selection of experiments suitable for the S-IVB workshop, single-launch configuration, and those suitable for longer duration configurations. The early orbital space station (EOSS) configuration has minimum experiment-weight restrictions, thus its program incorporates physiological degradation and medical/therapeutic experiments. When earlier data have indicated a need for more detailed experimentation, animal subjects will be chosen on the basis of their relevant subsystem similarity to that of man, for example, primates, for skeletal system study. The S-IVB workshop single-launch experiment program is described in Section 2.2.1; the experiment program for the EOSS configurations is described in Section 2.2.2.

2.1.3 Experiment Categories

There are essentially three categories of laboratory experiments: (1) primary physiological endpoint experiments, (2) secondary physiological endpoint experiments, and (3) medical/therapeutic experiments.

The primary physiological endpoint experiments will utilize one or two of such small, low-weight species as rodents in numbers large enough to achieve statistical validity of experimental results. The animals will be examined regularly to determine basic physiological deconditioning trends as a result of being exposed to weightlessness. The critical information to be obtained is the rate and degree of deconditioning before the physiological subsystem being observed stabilizes or adapts to zero g, 1/6 g, or whatever the experimental conditions may be. This physiological endpoint is defined as the point at which the change in a physiological system will reach an equilibrium and no further significant change will occur under a given set of specified environmental conditions. Physiological deconditioning can be defined as the changes that proceed to equilibrium, as a consequence of prolonged exposure to a lower level of stress. Conversely, physiological reconditioning is the adaptation to a point of equilibrium, to a higher level of stress (that is, back to 1 g or more).

These primary experiments will generally be performed on the S-IVB workshop, single-launch configuration. However, physiological deconditioning of specific systems may not reach physiological endpoints because of the limited mission duration, since the response time of each system to endpoint is different. These physiological systems which do not reach endpoints because of time limitations will be repeated as secondary endpoint experiments. An experimental-statistical technique for increased verification of experimental results could be gained by predicting endpoint data in these secondary experiments and discovering a correlation with observed data gathered. The secondary endpoint experiments are similar to the primary endpoint experiments, but they utilize animals chosen for specific physiological systems most comparable to man's for examining critical data points in detail. For example, miniature swine could be used to study the cardiovascular system, and primates could be used to study the musculo-skeletal system. Thus, it is necessary that the secondary physiological endpoint experiments utilize several larger varieties of animals in order to obtain deconditioning data which are most generalizable to man. These experiments would be performed on the long-term laboratory configurations.

The medical/therapeutic experiments will investigate rates of healing of a wide variety of injuries and diseases treated with standard therapies. Problems associated with healing in zero g which will require special investigation will be identified. The medical/therapeutic experiments will use animal species with specific physiological systems comparable to man's for given experiments. The experiments will investigate the effects of variation in g-level on injuries and diseases. For example, a fracture-healing experiment could be performed under three gravity conditions--zero g, 1/6 g, and 1-g--by use of a centrifuge system. The medical/therapeutic experiments can be performed on any of the long-duration mission configurations; however, statistical validity and degrees of sophistication will increase as a function of payload increase.

2.2 EXPERIMENT GROUP DESCRIPTIONS

Early laboratory configurations in this study have limited payload and mission duration. Later configurations are limited only by the 10,000 cu ft available in the S-IVB and the crew time available for work. Since early

configuration capabilities can meet the requirements imposed by critical physiological endpoint experiments with immediate relation to all manned spaceflights, these experiments were assigned to the earliest S-IVB workshop configuration. More detailed and sophisticated endpoint, reconditioning, medical, and therapeutic experiments are scheduled for the later S-IVB EOSS configurations. As configuration capabilities increase, the experiments generally become more elaborate and sophisticated. Example experiment programs for these more advanced configurations are shown in Section 2. 2. 2.

2. 2. 1 S-IVB Workshop, Single-Launch Experiment Program

The following example single-launch S-IVB workshop experiment program is based on the following assumptions:

1. The configuration is payload limited.
2. The configuration has a limited mission duration.
3. There is no requirement for artificial gravity (that is, centrifugation).
4. Exercise is required only for gathering heart-rate and respiratory-rate data under stress, as evidence of deconditioning.
5. Subjects will be rodents.
6. The only physiological measurements taken during the mission will be heart rate, respiratory rate, and body temperature. These measurements will be taken when the subjects are in a rested condition and also when they are in a stressed condition (that is, after exercise). Behavior changes will be observed and recorded photographically.
7. The category of experiment performed on this configuration is limited to the primary physiological endpoint experiment.

The 144 experimental subjects used in the example single-launch mission will be divided into three groups. Group A will consist of 60 subjects, Group B of 60 subjects, and Group C of the remaining 24 subjects. Subjects in Group A will be sacrificed in orbit in order to obtain periodic measurements of physiological system degradation. Subjects in Group B and Group C will be returned to Earth alive. The experimental procedures for each of the groups are as follows.

2.2.1.1 Group A

An equal number of subjects will be sacrificed at 5, 10, 15, 20, 24, and 28 days, as shown in Table 2-2. There will be 10 subjects in each of these subgroups. This procedure will yield data on physiological deconditioning caused by exposure to a zero-g environment for varying lengths of time.

2.2.1.2 Group B

All of the subjects in this group are returned to Earth alive. They are then reconditioned to a 1-g environment. They will be exercised daily until they have been returned to their preflight 1-g physiological levels. This level will be determined by the length of time a rat must exercise until his heart rate reaches a predetermined rate, that rate being the same as the control group's level. Rats will be sacrificed periodically during the reconditioning process in order to determine the rate of readaptation to 1 g.

2.2.1.3 Group C

All of the subjects in this group will be returned to Earth alive. They are then reconditioned to a 1-g environment normally, (that is, without excessive exercise). They are given an exercise period once a week (for example, on a treadmill turning at a specific rate) while their heart rate is measured concurrently. When it has been determined that the subjects have been

Table 2-2

SACRIFICE SCHEDULE FOR GROUP A SUBJECTS

(Mission Time in Days)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
				S					S					S					S					S				S		

S-IVB Workshop Activation — Experiment Time — Prepare for return

"S" indicates the sacrifice of 10 Group A subjects, assuming a 30-day mission and a 24-day experiment time.

reconditioned to 1-g physiological levels, they will be allowed to breed. Offspring will be examined for gross genetic changes (for example, atypical body formation). Experimental subjects and offspring both will be examined to determine any cytogenic changes (cytogentic changes occurring in the experimental subjects and which were transferred to their offspring).

The data from the Group A sacrifice schedule will establish a curve showing physiological deconditioning profiles resulting from exposure to a zero-g environment. The data from the Group B sacrifice schedule will establish a curve showing physiological reconditioning profiles after subjects have been returned to normal Earth environment.

Heart rate, respiratory rate, and body temperature in both rested and stressed conditions will be measured for all subjects. Heart-rate measurement devices and respiratory-rate measurement devices will have an accuracy of ± 10%; temperature measurement will have an accuracy of ± 0.1%. All instruments will provide readouts in real time. Minimum allowable time between successive readings is 12 hours. Motion pictures will be provided as required to document behavioral reactions to the experimental conditions.

The measurement program is summarized in Table 2-3.

Table 2-3

SINGLE-LAUNCH WORKSHOP EXPERIMENT MEASUREMENTS

In orbit
• Heart rate
• Respiration rate
• Temperature
• Vestibular disturbances (visual observation)
On Earth
• Organ weights and histopathological examination of subsystems
• Blood volume and plasma volume
• Blood composition
• Chromosome studies
• Bone demineralization
• Body mass and general examination
• Total body water

2. 2. 2 EOSS Experiment Programs

A candidate experiment program for EOSS missions is described in this section. Measurements for this program are summarized in Table 2-4.

2. 2. 2. 1 Secondary Endpoint Experiments

Information gathered from experiments utilizing physiological systems from rats may not be directly generalizable to the physiological systems of man. Therefore, the primary endpoint experiments will be repeated as secondary endpoint experiments, as described in Section 2. 1. 3, using larger animals selected for closer similarity to man in the various physiological systems.

If the secondary physiological endpoint experiment data are not significantly different from the primary experiment data, it can be assumed that man's physiological systems would follow the same general patterns.

If, however, data from primary and secondary endpoint experiments are significantly different, more sophisticated physiological deconditioning experiments must be performed, using animals most similar to man in terms of specific physiological systems.

2. 2. 2. 2 Medical/Therapeutic Experiments

The medical/therapeutic experiments will concentrate on those systems that one would expect to be significantly affected by the changes in the physiological subsystems. Physiological endpoints should first be determined as shown in Section 2. 2. 1 and Section 2. 2. 2. 1.

The medical/therapeutic experiments will follow the same logic as the previous experiments in terms of experimental design. A typical example of a medical/therapeutic experiment is shown in the following description of the EOSS candidate experiment program.

2. 2. 2. 3 General Experiment Program

The following example EOSS experiment program will investigate (1) physiological effects of long-term exposure to zero-g, (2) adequate antideconditioning

Table 2-4

EOSS EXPERIMENT PROGRAM--PHYSIOLOGICAL ENDPOINT
MEDICAL/THERAPEUTIC EXPERIMENTS

Physiological Subsystem Measurements	Environmental Stresses*									
		Traumatic tissue damage								
	No Trauma	Toxic inhalation	Fracture	Crushing wound	Contusion	Abrasion	Cut	Chemical burn	Thermal burn	Infection
Heart weight and histopathological examination	0	0	0	0	0	0	0	0	0	0
Heart rate	0	0	0	0	0	0	0	0	0	0
Blood volume and plasma volume	0	0					0	0	0	
Red blood cell mass	0	0	0				0	0	0	
Blood composition	0	0					0	0	0	0
Cardiovascular work capacity	0	0								0
Blood pressure	0	0	0	0	0	0	0	0	0	0
Hemostasis	0					0	0	0	0	0
Hemoglobin	0	0				0	0			0
Chromosome studies	0	0						0		
Lung weights and histopathological examination	0	0								0
Respiratory rate	0	0	0	0	0	0	0	0	0	0
Stomach, small intestine, large intestine weights, and histopathological examination	0	0								0
Food intake-waste output	0	0	0	0	0	0	0	0	0	0
Gastrointestinal motility	0	0		0						0

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Gastrointestinal pH	0	0		0						0
Skeletal weight and histopathological examination	0	0	0	0				0		0
Bone demineralization	0	0	0	0				0		0
Muscle mass weight and histopathological examination	0	0	0	0	0		0	0	0	0
Muscle strength	0	0	0	0	0		0	0	0	0
Gonad weights and histopathological examination	0	0						0		0
Kidney and liver weights and histopathological examination	0	0		0	0		0	0	0	0
Endocrine gland weights and histopathological examination	0	0	0	0	0	0	0	0	0	0
Body temperature measurement	0	0	0	0	0	0	0	0	0	0
Visual inspection of skin	0	0	0	0	0	0	0	0	0	0
Skin function	0	0				0		0	0	0
Otolith processes	0	0						0		0
Metabolic rate	0	0								0
Body mass and general examination	0	0	0	0	0	0	0	0	0	0
Traumatic shock resistance	0	0	0	0	0	0	0	0	0	0
Tissue biopsy	0	0	0	0	0	0	0	0	0	0
Total body water	0	0				0		0	0	0
CNS studies--sensory deafferentation	0	0								0
Embryological studies	0	0		0			0	0	0	0
Growth studies	0	0	0	0	0	0	0	0	0	0

0--Performed as an Orbital experiment.

*These stresses will be provided under different artificial gravity and different exercise levels.

or reconditioning procedures, and (3) the course of injury and disease in space. The experiment program will utilize the following species:

1. Rats (252).
2. Primates (12).
3. Swine (6).

Although they were not included in the representative experiment program, cats should be considered for experiments in vestibular mechanisms because of their highly sensitive vestibular system and as a follow-on to the work of Gerathewohl and von Beckh.

Of the 252 rats required for the mission, 56 will be used for a 56-day physiological deconditioning experiment. The 56 rats will be exposed to the zero-g environment without exercise or partial gravity (that is, centrifugation). One rat will be sacrificed every other day, and complete gross pathological and histopathological examinations will be performed in the orbiting facility, with the slide preparations being returned for Earth examination. After 56 days, half the number of rats used for the experiment will have been sacrificed. The remaining 28 deconditioned rats will be returned to Earth alive. After return to the ground, one rat will be sacrificed every 2 or 3 days and complete pathological examinations will be performed in order to determine reconditioning trends after return to a 1-g environment. The major considerations of the 56-day physiological deconditioning experiment are shown in Table 2-5.

The remaining 198 rats will be used in a long-term orbital medical experiment. The subexperiment categories and the number of rats assigned to each are shown in Table 2-6.

The rats will be placed in groups receiving different gravity levels (by means of a centrifuge) and different exercise levels. Experimental injury or disease will be applied to some subjects at the beginning of the mission before deconditioning begins, to others at approximately the midpoint of deconditioning, and to yet others near the endpoint of the deconditiong process. An example allocation for the 18 subjects used in the fracture-healing subexperiment is shown in Table 2-7. This experimental procedure enables the separation of the effects of g-level, exercise, and level of deconditioning on fracture-healing.

Table 2-5

PHYSIOLOGICAL DECONDITIONING EXPERIMENT

56 Subjects	
28 Subjects Decondition	28 Subjects Decondition
All subjects sacrificed in orbit	All subjects returned alive
Sacrifice one subject every two days	After subjects returned to ground, one subject sacrificed every two or three days during reconditioning program

Table 2-6

SUBJECT ALLOCATION FOR LONG-TERM MEDICAL EXPERIMENTS USING RATS

Subexperiment Categories	Number of Subjects Used*
Fracture	18
Thermal	18
Cut	18
Contusion	18
Radiation	18
Pulmonary irritation	36
Infection	36
Traumatic shock	36

*The subexperiment categories utilizing 18 subjects are verifications of similar experiments on primates and swine. Those using 36 subjects are not duplicated with other animals.

Table 2-7

SUBJECT ALLOCATION FOR MEDICAL FRACTURE-HEALING EXPERIMENT USING RATS

	No Exercise 0 g	No Exercise 1/6 g	No Exercise 1 g	Exercise 1 g
Fracture before deconditioning begins	2 subjects	2 subjects	2 subjects	2 subjects
Fracture at midpoint of deconditioning	2 subjects	2 subjects	2 subjects	0
Fracture near end-point of deconditioning	2 subjects	2 subjects	0	0

The other medical subexperiments (for example, cuts, contusions, radiation, and so forth) will utilize the same type of subject allocation as shown in Table 2-7, in order to determine the effects of different conditions on the healing process.

The 12 primate subjects will be divided into 3 groups. One group will be used to study the effects of radiation in orbit, another will be used to study fracture healing, and the third group will be used for the study of cerebral injury. The allocation of subjects to the various experimental conditions is shown in Table 2-8. All injuries will be inflicted early in the mission, before significant deconditioning has occurred.

Hematological, metabolic, and neurological studies will be performed on all subjects until the healing process is complete. When healing has occurred on a subject, it will be sacrificed and gross pathological and histopathological examinations will be performed.

The swine will be divided into three groups of two swine each. The experimental timeline for the three groups of swine is shown in Table 2-9.

Group 1 subjects will have a cut inflicted early in the mission before significant deconditioning has had time to occur. The cut will then be allowed to heal. One month is allowed as the time required for the healing process to be completed. During this period, hematological and metabolic studies will

Table 2-8

MEDICAL/THERAPEUTIC EXPERIMENTS
USING PRIMATES

	No Exercise 0 g	No Exercise 1/6 g	No Exercise 1 g	Exercise 1 g
Radiation*	1 subject	1 subject	1 subject	1 subject
Fracture	1 subject	1 subject	1 subject	1 subject
Cerebral injury	1 subject	1 subject	1 subject	1 subject

*Sublethal radiation dose with known recovery time.

be performed at regular intervals in order to determine any physiological degradations which might influence the healing process. If the cuts heal satisfactorily in 1 month, abrasions will be inflicted on different portions of the swine's anatomies. Again, hematological and metabolic studies will be performed regularly during the healing process. If the abrasions heal sufficiently in 1 month, 2nd and/or 3rd degree thermal burns will be inflicted and allowed to heal (estimated healing time, 2 months) followed by chemical burns which will also be allowed to heal (estimated healing time, 2 months).

This entire experimental procedure will require approximately 6 months. For the next 3 months of the mission, Group 1 subjects will be allowed to decondition without further traumatic injury. Hematological and metabolic studies will continue until the subjects are sacrificed, after approximately 9 months of the mission have elapsed. A complete gross pathology and histopathology will be performed in the orbiting facility at that time.

Group 2 swine will be subjected to traumatic injuries different from those in Group 1, but the same hematological and metabolic studies will still be performed at regular intervals. The Group 2 subjects will have contusions

Table 2-9

TIMELINE FOR SWINE EXPERIMENTS

	Months												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Group 1	Cut	Abrasion	Thermal burn		Chemical burn		No injury			Sacrifice*			
Group 2	Contusion		Crushing wound		No injury							Sacrifice*	
Group 3	No injury						Cut	Abrasion	Thermal burn		Chemical burn		Sacrifice*
							Contusion		Crushing wound		Sacrifice*		

*After sacrifice, each swine will be given a gross pathological and a histopathological examination.

inflicted early in the mission before deconditioning has begun. The time estimated for the contusions to heal is 2 months. When the contusions have healed, crushing wounds will be inflicted on different portions of the swine's anatomies. The time estimated for these wounds to heal is also 2 months. The subjects in Group 2 will then be allowed to decondition for 7 months more without further traumatic injury. During the 12th month of the mission, the subjects in Group 2 will be sacrificed, and complete pathological studies will be performed.

Swine in Group 3 will not be subjected to traumatic injury for the first 6 months of the mission. However hematological and metabolic studies will be performed at regular intervals in order to serve as a control group to Groups 1 and 2 in addition to providing basic physiological deconditioning data without traumatic injury. After 6 months, one subject in Group 3 will be exposed to the injury regimen of Group 1 and the other subject in Group 3 will be exposed to the injury regimen of Group 2. The former subject will be sacrificed during the 13th month of the mission, and the latter subject will be sacrificed during the 11th month as shown in Table 2-9. Complete pathological studies will be performed on both subjects. The Group 3 subjects will provide data on rate and effect of the healing process as a function of level of deconditioning. Differential healing rates might be evident in the deconditioned animals.

None of the swine will be exposed to partial gravity with a centrifuge, nor will they be exposed to different exercise schedules. If it is found that the healing times are different from the estimates, the experiment schedule will be adjusted accordingly.

In typical experiments of this type, the principal investigator could adjust the experimental design to satisfy additional requirements for control subjects.

2.3 EXPERIMENT SUBJECTS

2.3.1 Standard Laboratory Animals

Laboratory animals most commonly utilized for research are rodents (for example, rats, mice, and guinea pigs) and lagomorphs (hares, rabbits, and

pikas). Rodents are often the most convenient mammalian research animals and are especially adapted to genetic studies because of their short lifespan, rapid breeding, and the genetic purity obtained from long established colonies. Specific strains of rodents can be obtained to study diverse problems in nutrition, metabolism, immunology, genetics, and a variety of disease conditions. The small size and comparatively low metabolic demands of rodents make them prime subjects for space experiments. A comparatively large amount of baseline data exist concerning rodents.

The most commonly employed carnivores are dogs, cats, and ferrets. Dogs have been widely employed to study cardiovascular, renal, and respiratory physiology. Cats have been utilized often to study the physiology of vision, vestibular, hearing, and nervous responses.

Primates employed have been various species of monkeys (most often the rhesus) and chimpanzees. All primates are expensive and difficult to breed. Primate colonies and experimental centers established recently have provided much baseline data concerning these animals. From recent research on serology and congitive functions, there is a growing body of evidence that chimpanzees are man's closest relative.

Primates are most similar to man anatomically (such as the skeletal system), but not necessarily in the physiology of the nervous system. Remarkable similarities to man exist in embryological and reproductive physiology. Primates are subject to many of the pathogens of man, such as viruses, tuberculosis, and endoparasites. The chimpanzee, if utilized at about 6 years of age (under about 23 kilograms), is valuable for behavioral problems requiring manipulatory ability of the hand.

One of the most significant developments in recent years is the appearance of several breeds of miniature swine. Breeding and reduction in size has indicated that the miniature swine will not only be available in sufficient numbers, but will also be manageable laboratory animals. Research has demonstrated that remarkable similarities exist between man and miniature swine. Body weight, cardiovascular physiology, and wound healing are a few of the pertinent ones. Possibly swine are the animals of choice for studies

of the blood vessel wall, blood platelets, and blood coagulation. They develop spontaneous atherosclerosis that is topographically and morphologically similar to development in man. The coronary arteries are distributed as in man and are valuable for the study of myocardial and vascular changes following ligation and narrowing, notably the effects on collateral circulation.

Swine can develop ulcers similar to man. Swine are unique in their long period of deciduous and transitional dentition and in the form of the teeth. These oral characteristics as well as the type of mastication permit close extrapolation to human oral physiology and pathology.

Swine are omnivorous, can easily be made obese, are content to be sedentary, or can be made to exercise. Rheumatoid arthritis and other musculoskeletal pathologies are similar to man's. Incised wounds heal like those of man and daily biopsies can be performed without morbidity or mortality. Swine skin is similar to man's and allows comparisons in the study of allergic and ionizing radiation effects.

Basic data have been accumulated on more than three strains of miniature swine regarding mortality and recovery from ionizing radiations such as the late effects of neutron-gamma and beta radiation. Blood groups, analysis of heat loss, pulmonary blood-air barrier, germ-free techniques, more than 21 hematological and serum biochemical parameters, age-related changes, and chronic implanation of instruments are other areas of baseline data accumulated on miniature swine.

Miniature swine, as well as dogs, cats, and primates, present a special problem in waste disposal. Their excreta is of such a consistency that it is difficult to "sweep" against a filter. Research is required to develop a waste disposal system for animals of this type, which will function in space, yet will not restrain the animal's movement. Studies being performed for NASA in connection with the orbiting primate are expected to yield firm approaches to this problem.

2.3.2 Experiment Subject Selection and Rationale

In this section, standard white laboratory rats will be considered as subjects for the primary physiological endpoints to be performed on the S-IVB workshop, single-launch configuration. The rationale for choosing this approach

is that a large quantity of terrestrial baseline data have been accumulated on rats relatable to physiological deviations which could occur in a space environment. The rat could provide a means of determining conditioning and reconditioning trends for most physiological systems.

Curves can be obtained which describe the effects of an orbital environment on the major physiological systems of the rat. Data from several systems could be obtained until physiological deconditioning reaches an endpoint. For example, under zero-g conditions, differences could be expected in the length of time required for the various systems to adapt to zero g (for example, fluid shifts occur more rapidly than does calcium loss from osseous tissue). Adaptation curves for individual systems and subsystems can be exemplified by Figure 2-1. This curve illustrates an adaptation of a typical physiological system within physiological limits (that is, a decrease in calcium content within lower physiological normals and a return to a normal level). The rationale of the experiment would be to determine as accurately as possible when the physiological endpoints of specific systems and subsystems are reached, and the time interval required to return to normal.

If critical points were identified on a timeline base, these physiological adaptation processes, curves, and endpoints could give an index of basic adjustment of the rat to various stresses of the space environment.

Table 2-10 is a list of physiological systems to be considered for investigation. Animals which should be considered as prime candidates for investigation of physiological endpoint experiments also are listed.

The precise mix of laboratory animals would depend upon the needs of a particular experiment design. To keep within the bounds of a reasonable space laboratory operation, the limits on numbers of larger animals must be kept low. Possibly experiments could be repeated many times on each large animal (that is, swine and larger primate) and tests requiring sacrifice of these animals for pathological examination could be minimized. In the smaller animals, large numbers could be utilized in order to get statistically meaningful results and/or to permit the frequent sacrifice of animals at particular endpoints.

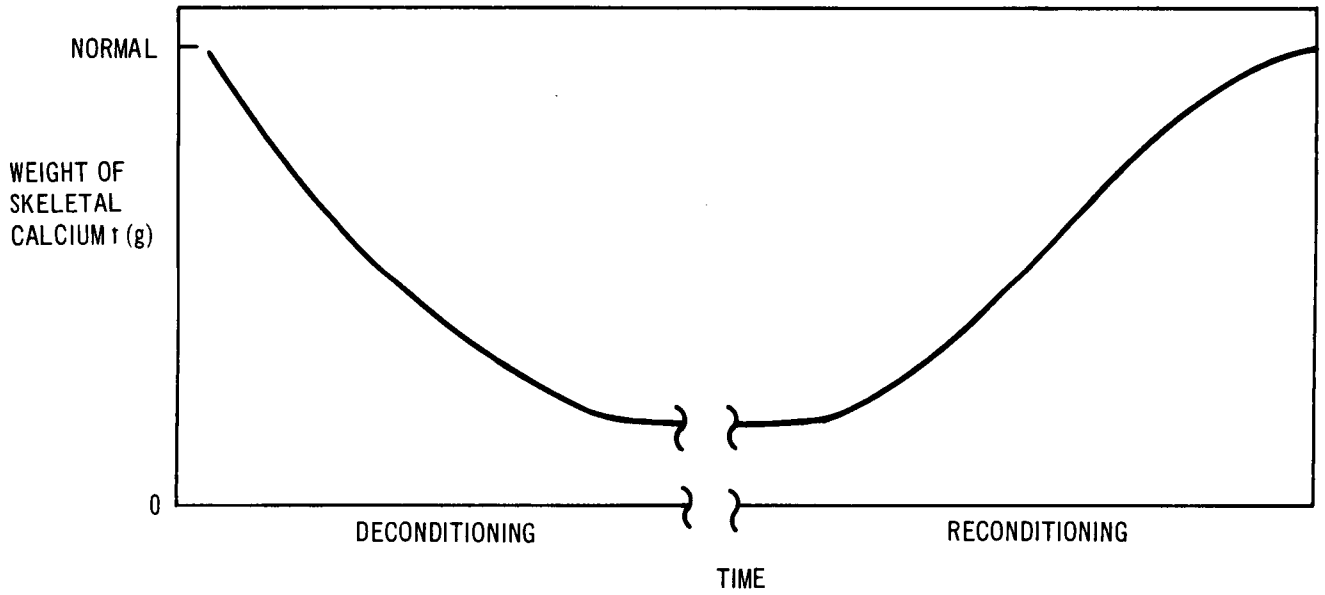

Figure 2-1. Hypothetical Adaptation Process

Table 2-10

ANIMALS CONSIDERED FOR USE ON THE SECONDARY PHYSIOLOGICAL ENDPOINT EXPERIMENTS

Physiological Endpoint Experiments	Animals Used
Musculoskeletal	Primate, cat, dog
Cardiovascular	Swine, primate
Skin	Swine, dog
Pulmonary	Rodent, primate
Renal	Primate
Hematological	Rodent, primate
Neurological	Primate, rodent
Endocrine	Primate, rodent, dog

Different types of animals could be utilized on a time-phase basis (one type per flight mission). However, as each species contributes uniquely, any delay resulting from time-phasing would tend to evaluate the results of the research program.

It is believed, however, that early S-IVB workshops can accommodate sufficient tradeoffs in numbers and species to ensure maximum value of the biology program. Time-phasing for the use of specific colonies of animals in later flights can be determined from the data derived from an optimum mix of numbers and species utilized on an early workshop. Section 2.3.4.3 describes a means by which a program director could determine what mix of numbers and species could be accommodated for a particular flight. Thus, test animals could be chosen in flexible arrays to satisfy the relationships between various experiment areas and the ultimate research goals of the space-biology program.

Table 2-11 lists the medical/therapeutic experiments considered for investigation on the advanced configurations and animals which are most comparable to humans for that particular experiment.

Table 2-11

ANIMALS CONSIDERED FOR USE ON THE MEDICAL/THERAPEUTIC EXPERIMENTS

Medical/Therapeutic Experiments	Animals Used
Cuts	Swine, dog
Abrasions	Swine, dog
Contusions, crushing wounds	Swine, primate
Fractures	Primate, cat, dog
Burns	Swine, dog
Pulmonary irritation	Rodent, primate
Traumatic shock	Rodent, primate
Radiation exposure	Rodent, primate
Infection	Rodent, primate

2.3.3 Characteristics of Selected Subjects

Several characteristics of the selected animals for the experiments are shown in Table 2-12.

2.3.4 Animal Support Requirements

This section presents (1) environmental control/life support (EC/LS) requirements for animals, (2) these EC/LS requirements expressed in "rat equivalents", and (3) a method of studying varying animal populations in a system of known capacity or to determine the capacity required for a new system.

It should be pointed out that the data included in this section are presented for the purpose of sizing EC/LS systems, and should not be considered precise biological values.

2.3.4.1 EC/LS Requirements for Animals

The EC/LS requirements for seven candidate subjects are presented in Table 2-13. To develop this table, data on animal body weight, diet composition, weight of food intake, and amount of water consumed were obtained

Table 2-12

SUBJECT CHARACTERISTICS

Species	Housing Volume (cu ft)	Rectal Temp (°F)	Heart Rate (per min)	Resp Rate (per min)	Oestrus Cycle (days)	Mating Age (days)	Room Temp (°F)	Humidity (%)	Life Span (years)
Mouse	0.3	99.3	600	163	4-5	42-56	68-72	50-60	2
Rat	0.4	99.5	300	210	4-5	90-110	65-70	45-55	3
Dog	20.0	101.4	95	15	5-14	540	72	45-60	14
Cat	6.0	101.6	130	24	15-28	300	72	40-45	13
Primate	10.0	101.1	100	19	28	547-910	68-72	40-50	15
Swine (References 3 and 4)	35.0	99.8	80-127	20	18-24	150-240	65-70	40-50	15

Tabl

EC/LS REQUIREM

Animal	Body Weight*	Food Diet Composition* (%)		Weight of Food Intake* per day	Weight of Solids Output** per day	Amo Dri Wa Cons (ml/
Mouse	20g	Protein	13.7	5g	0.54g	
		Fat	3.5			
		Carbohyd	49.0			
		Fiber	1.5			
		Water	32.3			
Rat	250g	Protein	13.7	20g	2.18g	2
		Fat	3.5			
		Carbohyd	49.0			
		Fiber	1.5			
		Water	32.3			
Cat	3Kg	Protein	20.0	120g	16.16g	16
		Fat	7.5			
		Carbohyd	38.0			
		Ash	1.5			
		Water	33.0			
Dog	15Kg	Protein	15.0	300g	34.17g	70
		Fat	7.5			
		Carbohyd	43.0			
		Fiber	1.5			
		Water	33.0			
Rhesus Monkey	3Kg	Protein	27.3	120g	29.77g	29
		Fat	4			
		Fiber	2.8			
		Carbohyd	44.1			
		Free N_2	4.1			
		Ash	9.3			
		Water	8.4			
Adult Chimpanzee	37Kg	Protein	27.3	290g	72.32g	1,47
		Fat	4			
		Fiber	2.8			
		Carbohyd	44.1			
		Free N_2	4.1			
Immature Chimpanzee	18Kg	Ash	9.3	200g	49.88g	98
		Water	8.4			
Miniature Swine	55Kg	Protein	15	1.8Kg	205.4g	2,6(
		Fat	7.5			
		Carbohyd	43.0			
		Fiber	1.5			
		Water	33.0			

*Data obtained from library research

**Calculated from formula: Waste = Wt food eaten/day + Wt O_2 utilized/day - Wt CO_2 pr

***Data calculated from metabolic equations in Reference 5.

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LENTS FOR ANIMALS

unt of nking ater umed day)	Water: Amount of Water in Food (ml/day)	Water: Total Water Consumed* (ml/day)	Water: Metabolic Water Produced*** (ml/day)	Water: Total Water Output ml/day	Other: Oxygen Intake*** (l/day)	Other: Carbon Dioxide Output*** (l/day)	Other: Heat Output*** (kcal/day)
3.38	1.62	5.0	1.73	6.73	2.88	2.66	14.05
1.54	6.46	31	6.93	37.93	11.52	10.64	56.22
0.4	39.6	200	42.42	242.4	74.7	65.4	358.3
1.0	99.0	800	108.2	908.2	185.2	164.5	895
0.0	10.0	300	45.36	345.4	80.34	73.6	384.7
5	24.4	1,500	109.6	1,609.6	194.2	177.8	929.7
3.4	16.8	1,000	75.6	1,075.6	133.9	122.6	641.2
)	594	3,200	649.1	3,849.1	1,111.0	986.9	5,371.0

oduced/day - Wt metabolic H_2O produced/day

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from library research. However, the data on these items were very inconsistent and, therefore, their average values were calculated and these values appear in Table 2-13.

Four other factors included in the table, metabolic water produced, oxygen intake, carbon dioxide output, and heat output, were calculated from metabolic equations (Reference 5).

The weight of solids output was calculated from the formula:

$$\text{Waste} = P(\eta p) + F(\eta f) + C(\eta c) + O_2 + B - CO_2 - H_2\text{Omet.}$$

where:

P	=	weight of protein eaten
ηp	=	efficiency of protein digestion
F	=	weight of fat eaten
ηf	=	efficiency of fat digestion
C	=	weight of carbohydrate eaten
ηc	=	efficiency of carbohydrate digestion
O_2	=	weight of oxygen intake
CO_2	=	weight of carbon dioxide output
B	=	weight of indigestible material eaten
$H_2\text{Omet}$	=	weight of metabolic water produced

2.3.4.2 Rat Equivalents

Table 2-14 expresses animal EC/LS requirements using the rat's values as a baseline of 1. For example, an animal that requires an amount of oxygen equal to 10 times that of a rat will have a "rat equivalent" of 10 for oxygen intake.

2.3.4.3 Animal Colony EC/LS Graph

The information contained in the rat equivalent table has been used to prepare a graph (Figure 2-2) which is useful in the design-study phase of animal-colony EC/LS systems. It may be used to study varying animal populations

Tab

RAT EC

Animal	Body Weight	Weight of Food Intake	Weight of Solids Output	Amount of Water Consumed	A of i
Mouse	0.08	0.25	0.25	0.14	
Rat	1.00	1.00	1.00	1.00	
Cat	12.00	6.00	7.41	6.54	
Dog	60.00	15.00	15.67	28.56	1
Rhesus Monkey	12.00	6.00	13.65	11.82	
Adult Chimpanzee	148.00	14.50	33.17	60.10	
Immature Chimpanzee	72.00	10.00	22.88	40.07	
Miniature Swine	220.00	90.00	94.22	106.19	9

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ble 2-14
QUIVALENTS

mount Water n Food	Total Water Consumed	Metabolic Water Produced	Total Water Output	Oxygen Intake	Carbon Dioxide Output	Heat Output
0.25	0.16	0.25	0.18	0.25	0.25	0.25
1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.13	6.45	6.12	6.39	6.48	6.15	6.37
5.32	25.81	15.61	23.94	16.08	15.46	15.92
1.55	9.68	6.54	9.11	6.97	6.92	6.84
3.78	48.39	15.81	42.44	16.86	16.71	16.54
2.60	32.26	10.91	28.36	11.62	11.52	11.40
1.95	103.22	93.66	101.48	96.44	92.75	95.53

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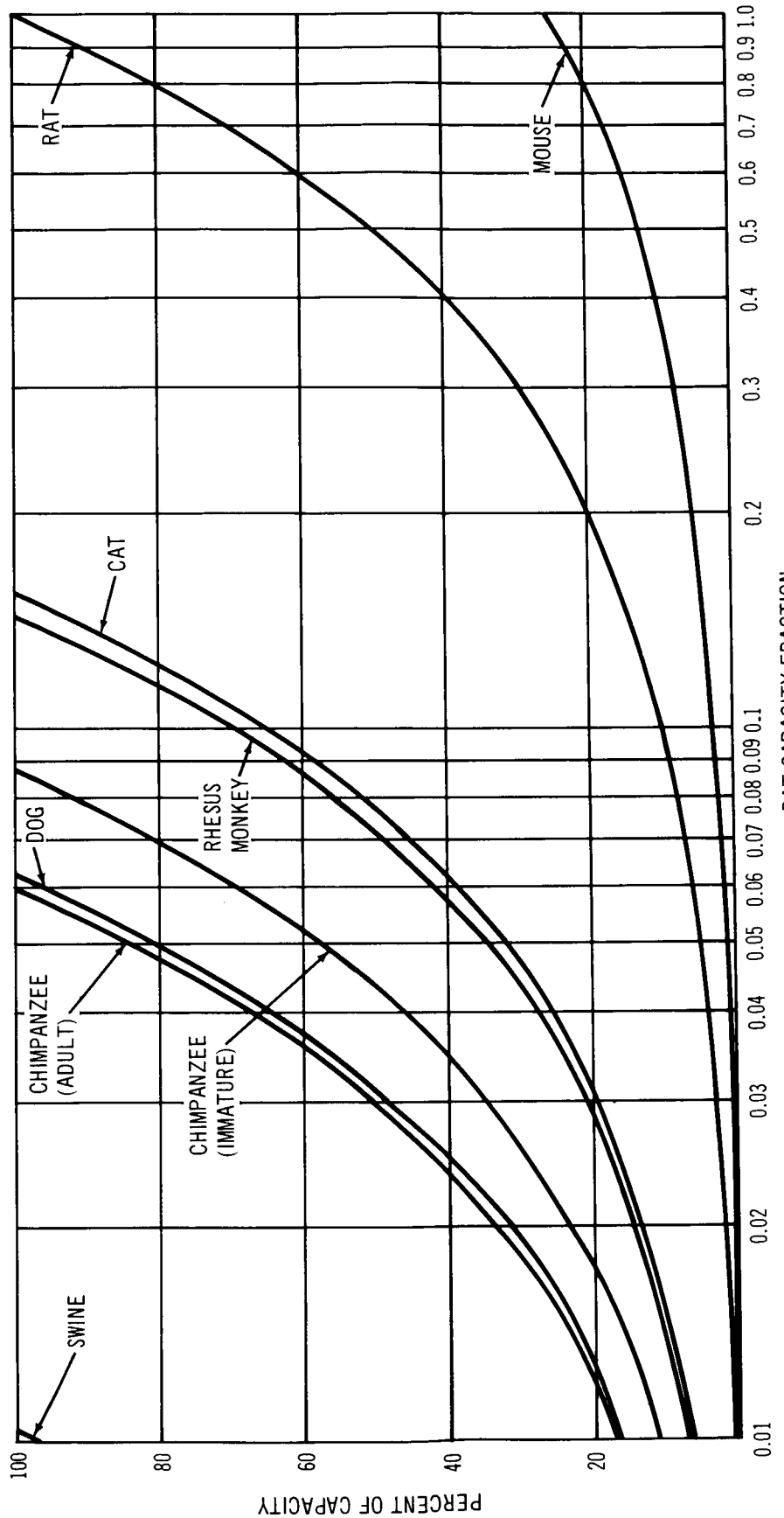

Figure 2-2. Animal Colony EC/LS Graph (Based on O_2 Intake)

in a system of known capacity, or to determine the capacity required for a new system. "Capacity" means the maximum number of animals that an EC/LS system can provide with oxygen, heat removal, CO_2 removal, and so forth. Expressing the capacity of an EC/LS system in terms of the number of 250-g rats it will accommodate is an arbitrary choice of convenience. Similar graphs could be prepared using any other animal as the unit. Note that the application of the graph is limited to design study only, and is based on average data obtained from current literature. Detailed design must concern itself with the specific requirements of the animals being considered.

The "rat equivalent" of oxygen-intake requirement for each animal was used in the preparation of the graph. This is the highest requirement of five, closely related characteristics--weight of food intake, carbon-dioxide output, heat output, oxygen intake, and metabolic water produced.

The animal-colony, EC/LS graph, shown in Figure 2-2 is a set of curves which shows the number of the animal being considered (expressed as a fraction of the total number of 250-g rats which the system will accommodate), as a function of the percentage of the total system capacity which that number will require.

The rat-capacity fraction is derived as follows:

The rat equivalent, E_R for animal "A" is:

$$E_R = \frac{\text{"A" requirement}}{\text{rat requirement}}$$

The quantity of animal "A" which may be accommodated by a system which has a capacity of x rats is

$$\text{number of "A"} = \frac{x}{E_R}$$

The fraction $\frac{1}{E_R}$ is the rat-capacity fraction.

The information has been plotted on semilog paper for clarity.

Three applications of the animal-colony graph are described in the following paragraphs.

Example 1

In a given system with a capacity of 150 rats (250 g), it is desired to know the quantity of animals which may be accommodated if the system capacity is allocated as follows:

1. Rhesus monkey--50%
2. Chimpanzee (immature)--25%
3. Rat--25%

At the graph's 50% capacity line and on the rhesus-monkey curve, the rat-capacity fraction is 0.071. Multiplication of the rat capacity (150) by this fraction gives

$$0.071 \times 150 = 10.65 \text{ rhesus monkeys}$$

Similarily, the 25% line gives

$$0.0215 \times 150 = 3.25 \text{ chimps,}$$

and $$0.25 \times 150 = 37.5 \text{ rats}$$

These numbers may be adjusted to 11, 3, and 38 for study.

Example 2

In a given system with a capacity of 500 rats (250 g), it is desired to study a program composed of 8 adult chimps, 8 immature chimps, and 24 rhesus monkeys. The system capacity is determined as follows.

Eight adult chimps in a system with a capacity of 500 rats, gives a rat-capacity fraction of

$$\frac{8}{500} = 0.016$$

At 0.016 on the graph, the adult chimp curve shows that 27% of the capacity will be required for the eight adult chimps.

Similarily, the 8 immature chimps will require 18% of the capacity and the 24 rhesus monkeys will require 33% of the capacity. Thus, 78% of the capacity has been consumed. The balance of 22% may be filled with 110 rats, or an equivalent quantity of other animals, by the method of Example 1.

Example 3

It is desired to size a system in which 80% of the capacity will be devoted to 40 rhesus monkeys. At the 80% line on the graph, the rhesus-monkey curve, gives a rat-capacity fraction of 0.115.

Because $$\frac{40}{\text{rat capacity}} = 0.115,$$

the system must be sized for a capacity of 350 rats (250 g). The remaining 20% of capacity may be allocated by the method of Example 1.

2.3.5 Control Group Requirements

Ground controls will be required for each experiment performed in orbit. Although each principal investigator would specify his own control groups, commensurate with his experimental design, two sets of controls should be provided for typical cases. All ground controls should receive training and preconditioning identical to the experimental subjects. The following are typical controls:

1. Control Group No. 1--Exposure to ground, normal regime only.
2. Control Group No. 2--Exposure to approximate flight environment under terrestrial conditions.

The experimental group and both control groups should be matched in terms of species, age, weight, sex, and experience. To the greatest extent possible, animals from the same litter should be utilized, each litter should be divided equally among the three groups (the split-litter technique).

All measurements taken on the experimental group should be taken in the exact manner on both control groups. To some extent, experimental subjects can serve as their own controls, as in hematological and urine samples taken before flight and in flight.

Through the use of control groups, an effort should be made to validate data obtained from animals in simulated-space conditions on Earth by comparison with the same data obtained from animals in actual space conditions. Success in this effort will provide significant benefits to the research programs.

2.3.6 Preconditioning Requirements

All experimental and control animals must be chosen from standard laboratory animals and must be thoroughly examined for good health. In some cases, experimenters may desire to use germ-free animals. The animal subjects should be accustomed to handling by the experimental workers, and should not have been subjected to unusual physical or psychological stress.

Special conditioning will be necessary to train animals to eat and drink from water and food dispensers designed for operation in zero g. Individual experiments may impose specific behavorial preconditioning requirements (for example, such as exercising on exercise devices designed for weightlessness states and making proper contact with the electrodes at the proper time for obtaining physiological data.)

2.4 EXPERIMENT SUPPORT REQUIREMENTS

This section presents a discussion of (1) laboratory scientific equipment, (2) experiment data requirements, (3) experiment housekeeping equipment, and (4) personal equipment.

2.4.1 Laboratory Scientific Equipment

Table 2-15 illustrates the general laboratory equipment required to perform the physiological endpoint and medical/therapeutic experiments. Table 2-16 shows the measurement equipment required to perform these types of experiments. Note that these tables represent general requirements only. When specific experiments are designed in detail, precise equipment requirements can be generated.

Table 2-17 illustrates the experiment measurements required to perform general categories of experiments. Table 2-18 shows the measurement equipment required to take these measurements.

Tab

EXPERIMENT SUPPOR

LABORATORY EQ

Douglas Number	Experiment	1 Voice Tape Recorder	2 Animal Restraints	3 Animal Centrifuge	4 Microscope	5 Slide and Tissue-Staining Kit	6 Syringes	7 Microtomes	8 Film-Developing Kit	9 Fluid-Handling Equipment	10 Specimen-Preservation Device	11 Specimen-Storage Device
	Physiological End-Point											
2443	Cardiovascular	x	x	x	x	x	x	x	x	x	x	x
2444	Pulmonary	x	x	x	x	x	x	x			x	x
2445	Musculoskeletal	x	x	x	x	x	x	x	x		x	x
2446	Neurological	x	x				x					
2447	Gastro-intestinal	x	x	x	x	x	x	x	x	x	x	x
2448	Endocrine	x	x	x	x	x		x	x	x	x	x
2449	Renal	x	x	x	x	x	x	x	x	x	x	x
	Medical/Therapeutic											
2451	Course of Injury	x	x	x	x	x	x	x	x	x		x
2452	Treatment of Injury	x	x	x	x	x	x	x	x	x		
2453	Course of Infection	x	x	x	x	x	x	x	x	x		
2454	Treatment of Infection	x	x	x	x	x	x	x	x	x		

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T EQUIPMENT (GENERAL)

UIPMENT (GENERAL)

12	Monkey Exerciser																				
13	Rat Exerciser																				
14	Video Camera (TV)																				
15	Movie Camera																				
16	Polaroid Camera																				
17	Refigerated Centrifuge	x	x																		
18	Timer	x	x																		
19	50-100x Lens																				
20	Impact Sled																				
21	Fracture-Treatment Kit																				
22	Shock-Treatment Kit																				
23	Burn-Treatment Kit																				
24	Cut-Treatment Kit																				
25	Contusion-Treatment Kit																				
26	Radiation-Treatment Kit																				
27	Pulmonary-Irrit'n Treatment Kit																				
28	Infection-Treatment Kit																				

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Table

EXPERIMENT SUPPORT EQ

LABORATORY EQUIPM

Douglas Number	Experiment	1 Histopathology Kit	2 Mass Deter. Device (Micro)	3 Recorders, Plotters	4 Radiation Shielding	5 Thermistor	6 Stethoscope	7 Mass Deter. Device (Macro)	8 Radioautography Equipment	9 Gas Chromatograph	10 Spectrophotometer	11 Sphygmomanometer	12 EKG	13 Bone Densitometer/X-ray	14 Signal Conditioner	15 Amplifier	16 Evan's Blue Dye
	Physiological Endpoint																
2443	Cardiovascular	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
2444	Pulmonary	x	x	x		x	x	x		x		x	x		x	x	
2445	Musculoskeletal	x	x	x	x	x			x					x	x	x	
2446	Neurological			x		x									x	x	
2447	Gastro-intestinal	x	x	x	x	x	x	x	x	x					x		x
2448	Endocrine	x	x	x	x	x	x	x	x	x		x	x		x	x	
2449	Renal	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Medical/Therapeutic																
2451	Course of Injury	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2452	Treatment of Injury	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2453	Course of Infection	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2454	Treatment of Infection	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

2-16

UIPMENT (MEASUREMENT)

ENT (MEASUREMENT)

18 Deuterium Oxide	19 Auto. Cell Counter	20 Colorimeter	21 Blood-Cell-Counting Kit	22 Hemostasis Kit	23 Ballistocardiogram	24 Digital/Limb Plethysmograph	25 Impedance Pneumograph	26 Respiration Flowmeter	27 Electromyograph	28 EEG Sensors	29 Size Determination Kit	30 Auto. Plate Scan Counter	31 Tissue Biopsy Kit	32 Urinalysis Kit	33 Catheter and Intubation	34 Hemocytometer	35 Otoscope/Ophthalmoscope	36 Reflex Hammer	37 Hemoglobinometer	38 Ergometer	39 Humistor	40 pH Meter	41 Gastrointestinal Tubes
x	x	x	x	x	x		x	x				x		x	x	x	x	x	x				
					x		x	x															
									x											x			
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x		x												x	x							x	x
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x	x	x	x		x		x	x				x		x	x	x					x		
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x	x	x	x	x			x	x	x		x	x		x	x	x	x	x	x	x	x	x	x
x	x	x	x	x			x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x

Tab

EXPERIMEN

MEASUREM

Douglas Number	Experiment	1 Heart Weight and Histopath. Exam	2 Heart Rate	3 Blood Volume and Plasma Volume	4 Red-Blood-Cell Mass	5 Blood Composition	6 Cardiovascular Work Capacity	7 Blood Pressure	8 Hemostasis	9 Hemoglobin	10 Chromosome Studies	11 Lung Wt and Histopath. Exam	12 Respiration Rate
	Physiological Endpoint												
2443	Cardiovascular	x	x	x	x	x	x	x	x	x	x		x
2444	Pulmonary		x				x					x	x
2445	Musculoskeletal												
2446	Neurological												
2447	Gastro Intestinal												
2448	Endocrine		x					x					x
2449	Renal		x	x	x	x	x	x					x
	Medical/Therapeutic												
2451	Course of Injury		x	x	x	x	x	x	x	x	x		x
2452	Treatment of Injury		x	x	x	x	x	x	x	x			x
2453	Course of Infection		x	x	x	x	x	x	x	x			x
2454	Treatment of Infection		x	x	x	x	x	x	x	x			x

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le 2-17

T MEASUREMENTS

ENTS REQUIRED

13 G.I. Tract Wt and Histopath. Exam	14 Food Intake - Waste Output	15 Gastro-intestinal Motility	16 Gastro-intestinal pH	17 Skeletal Wt and Histopath. Exam	18 Bone Demineralization	19 Muscle Mass Wt and Hist. Exam	20 Muscle Strength	21 Genital Gene Changes	22 Gonad Wt and Histopath. Exam	23 Kidney and Liver Wt and Hist. Exam	24 Endocrine Gland Wt and Hist. Exam	25 Body Temperature	26 Visual Inspection of Skin	27 Skin Function	28 Otolith Process	29 Metabolic Rate	30 Body Mass and General Examination	31 Traumatic-Shock Resistance	32 Tissue Biopsy	33 Total Body Water	34 CNS Studies - Sensory Deafferentation	35 Embryological Studies	36 Growth Studies
												x					x			x			
												x				x							
				x	x	x	x					x											
												x			x						x		
x	x	x	x									x				x				x			
									x	x	x	x				x	x					x	x
	x			x	x	x				x		x		x		x				x			
		x	x		x		x	x				x	x	x	x	x	x	x	x	x	x	x	x
	x	x	x		x		x					x	x	x	x	x	x	x	x	x	x	x	x
	x	x	x				x					x	x	x		x	x			x		x	x
	x	x	x				x					x	x	x		x	x			x	x	x	x

Table 2-18 (E

MEASUREMENT

	Measurement	1 Histopathology Kit	2 Mass Deter. Device (Micro)	3 Recorders, Plotters	4 Radiation Shielding	5 Thermistor	6 Stethoscope	7 Mass Deter. Device (Macro)	8 Radioautography Equipment	9 Gas Chromatograph	10 Spectrophotometer	11 Sphygmomanometer	12 EKG
1	Heart Weight and Histopathological Examination	x	x										
2	Heart Rate												x
3	Blood-Volume and Plasma Volume			x	x					x	x		
4	Red-Blood-Cell Mass				x					x	x		
5	Blood Composition			x							x		
6	Cardiovascular Work Capacity			x			x			x		x	x
7	Blood Pressure						x					x	
8	Hemostasis												
9	Hemoglobin										x		
10	Chromosome Studies												
11	Lung, Weight, and Histopathological Examination	x	x										
12	Respiration Rate			x									
13	Gastrointestinal Tract Weight and Histopathological Examination	x	x										
14	Food Intake-Waste Output		x	x									
15	Gastrointestinal Motility			x			x						
16	Gastrointestinal pH												
17	Skeletal Weight and Histopathological Examination	x	x										

EQUIPMENT

LABORATORY EQUIPMENT (MEASUREMENT)

13 Bone Densitometer/X-ray	14 Signal Conditioner	15 Amplifier	16 Evan's Blue Dye	17 Hematocrit Tubes	18 Deuterium Oxide	19 Auto. Cell Counter	20 Colorimeter	21 Blood-Cell-Counting Kit	22 Hemostasis Kit	23 Ballistocardiogram	24 Digital/Limb Plethysmograph	25 Impedance Pneumograph	26 Respiration Flowmeter	27 Electromyograph	28 EEG Sensors	29 Size Determination Kit	30 Auto. Plate Scan Counter	31 Tissue Biopsy Kit	32 Urinalysis Kit	33 Catheter and Intubation	34 Hemocytometer	35 Otoscope/Ophthalmoscope	36 Reflex Hammer	37 Hemoglobinometer	38 Ergometer	39 Humistor	40 pH Meter	41 Gastrointestinal Tubes
	x																											
			x	x	x		x																					
			x	x	x																							
						x		x									x				x				x			
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	x	x										x																
																											x	x

Table 2-18

	Measurement	1 Histopathology Kit	2 Mass Deter. Device (Micro)	3 Recorders, Plotters	4 Radiation Shielding	5 Thermistor	6 Stethoscope	7 Mass Deter. Device (Macro)	8 Radioautography Equipment	9 Gas Chromatograph	10 Spectrophotometer	11 Sphygmomanometer
18	Bone Demineralization				x				x			
19	Muscle Mass Weight and Histopathological Examination	x	x									
20	Muscle Strength			x								
21	Genital Gene Changes	x										
22	Gonad Weights and Histopathological Examination	x	x									
23	Kidney and Liver Weights and Histopathological Examination	x	x									
24	Endocrine Gland Weights and Histopathological Examination	x	x									
25	Body Temperature			x		x						
26	Visual Inspection of Skin											
27	Skin Function			x		x						
28	Otolith Processes			x								
29	Metabolic Rate		x					x		x		
30	Body Mass and General Examination				x		x	x				
31	Traumatic-Shock Resistance						x	x				x
32	Tissue Biopsy	x										
33	Total Body Water				x			x	x			
34	CNS Studies--Sensory Deafferentation											
35	Embryological Studies	x	x		x				x			
36	Growth Studies							x				

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(Page 2 of 2)

LABORATORY EQUIPMENT (MEASUREMENT)																														
	12 EKG	13 Bone Densitometer/X-ray	14 Signal Conditioner	15 Amplifier	16 Evan's Blue Dye	17 Hematocrit Tubes	18 Deuterium Oxide	19 Auto. Cell Counter	20 Colorimeter	21 Blood-Cell-Counting Kit	22 Hemostasis Kit	23 Ballistocardiogram	24 Digital/Limb Plethysmograph	25 Impedance Pneumograph	26 Respiration Flowmeter	27 Electromyograph	28 EEG Sensors	29 Size Determination Kit	30 Auto. Plate Scan Counter	31 Tissue Biopsy Kit	32 Urinalysis Kit	33 Catheter and Intubation	34 Hemocytometer	35 Otoscope/Ophthalmoscope	36 Reflex Hammer	37 Hemoglobinometer	38 Ergometer	39 Humistor	40 pH Meter	41 Gastrointestinal Tubes
		x																												
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43B

Table 2-19 is a brief description of laboratory-measurement-equipment characteristics; Table 2-20 briefly describes general, laboratory-equipment characteristics.

The information provided by this portion of the study has been used in the engineering study to define experiment, program-support requirements.

2.4.2 Experiment Data Requirements

2.4.2.1 Motion Picture Requirements

The provision for taking motion pictures will be provided for the following reasons:

1. To determine the adequacy of the on-board equipment.
2. To maintain a record of the animal-subjects' behavioral adaptation to the weightless environment.
3. To record any specific difficulties in the animal/machine interface, such as problems in the animal's operation of the feeding device.
4. To record any unplanned events of significance to the mission or to the planning of future missions.
5. To obtain supplementary information about growth and weight changes, condition of fur, brightness of eyes, and so forth.

2.4.2.2 Baseline Physiological Measurements

The following baseline physiological measurements should be taken:

1. Heart rate measured with implanted telemetry sensor.
2. Respiration rate measured with implanted telemetry sensor.
3. Kinesthetic activity level or amount of exercise measured by a counter on the exercise device.

2.4.2.3 Intermittent Measurements

The following intermittent measurements should be taken:

1. Weight--Subject mass will be determined about once a week using a centrifuge with appropriate equipment, or an oscillating device.
2. Size--Girth, length, and limb measurements may be periodically made with a tape measure and micrometers.

Table 2-19 (Page 1 of 3)

DESCRIPTION OF LABORATORY EQUIPMENT (MEASUREMENT)

	Equipment Nomenclature	Power (W)	Weight (lb)	Volume (cu in.)	Gravity Dependent	Remarks
1	Histopathology Kits (4)	0	4	2,000	Yes	Scalpel, hemostats, tissue scissors, probes, soap, dressings, sheets, antiseptics, sutures, etc.
2	Mass-determination device (micro)	0	1.0	200	No	Range 0.1 g to 4 Kg
3	Recorders and plotters	10	2	600	No	Direct writing type
4	Radiation shielding	0	2	50	No	
5	Thermistor	0.5	0.1	4	No	Self-contained, solid-state
6	Stethoscope	0.1	0.25	25	No	Recommend electronic type
7	Mass-determination device (macro)	0	5.0	9,000	No	Range 2-90 Kg
8	Radioautography Equip.	0	5	500	No	Radioactive isotopes required; problem of short half-life
9	Gas Chromatograph	30	5	600	No	Fluid-handling problems
10	Spectrophotometer	75	4	250	No	
11	Sphygmomanometer	0.15	2.3	170	No	Recommend Douglas type
12	EKG	12	3	200	No	Direct writing recommende
13	Bone densitometer/X-ray	1,000	40	3,500	No	Requires X-ray; 1,000 W for max. of 10 sec

Table 2-19 (Page 2 of 3)

Equipment Nomenclature	Power (W)	Weight (lb)	Volume (cu in.)	Gravity Dependent	Remarks
14 Signal conditioner	5	0.5	36	No	
15 Amplifier	5	3	800	No	
16 Evans blue dye	0	0.12	20	No	
17 Hematocrit tubes (12)	0	0.12	5	Yes	Disposable type; micro-hematocrits desirable
18 Deuterium oxide	0	0.12	10	No	
19 Auto. cell counter	250	30	3,500	Yes	Coulter-counter type
20 Colorimeter	13	4.5	432	No	Development of fluid-transfer techniques required
21 Blood-Cell-Counting Kit	0	0.12	20	Yes	Capillary tubes, cell diluting fluids
22 Hemostasis Kit	0	5.2	500	Yes	Lancets, capillary tubes, test tubes
23 Ballistocardiogram	30.0	5	9,000	No	
24 Digital limb plethysmograph	0.5	4.0	20	No	
25 Impedence pneumograph	0.15	0.5	15	No	
26 Respiration flowmeter	1.0	3	80	No	Resp. valve, hoses, mouthpiece; O_2 and CO_2 sensors
27 Electromyograph	5	0.13	5.0	No	Adjustable to fit different animals
28 EEG Sensors	5	2	500	No	
29 Size Determination Kit	0	0.5	200	No	Micrometers, tape measure (anthropometric)

Table 2-19 (Page 3 of 3)

	Equipment Nomenclature	Power (W)	Weight (lb)	Volume (cu in.)	Gravity Dependent	Remarks
30	Auto. plate scan counter	10	20	500	Yes	
31	Tissue biopsy Kit	250	0.25	2	No	Punch type
32	Urinalysis Kit	0	1	30	No	Hand-held refractometer, spot test papers
33	Catheter and Intubation Kit	0	0.25	100	No	Various-size polyethylene tubes
34	Hemocytometer	0	0.5	30	Yes	Requires noncapillary and photographic techniques
35	Otoscope/Ophthalmoscope	0	0.25	10	No	May also be used as proctoscope
36	Reflex hammer	0	0.25	10	No	
37	Hemoglobinometer	5	0.25	8	Yes	American Optical type
38	Ergometer	0	35	3,500	Yes	Adjustable to fit different animals
39	Humistor	0.5	0.1	4	No	Bridge circuit, solid-state
40	pH meter	0.1	1.5	150	No	Uni-polar type (self-contained, portable)
41	Gastro-intestinal tubes (10)	0	0.25	10	No	Disposable tubes, various sizes

Table 2-20 (Page 1 of 2)

DESCRIPTION OF LABORATORY EQUIPMENT (GENERAL)

No.	Equipment Nomenclature	Power (W)	Weight (lb)	Volume (cu in.)	Gravity Dependent	Remarks
1	Voice tape recorder and tapes	50	5.0	1,200	No	Portable, self-contained
2	Animal restraints	0	20.0	1,800	No	Various sizes and types for all animals used
3	Animal centrifuge (macro)	210	75	4-ft cylindrical section of S-IVB	No	
4	Microscope and accessories	10	5.0	900	Yes	Head stabilization required (bite plate or chin rest)
5	Slide and Tissue-Staining Kit (automated)	5	5.0	1,750	Yes	Should be automated; includes stains
6	Syringes (12)	0	1	20	No	Use vacuum-type syringe
7	Microtome	25	2.5	400	No	Used with specimen-preservation device; freezing type
8	Film-Developing Kit	0	4	500	Yes	Fluid-handling problems
9	Fluid-handling equipment	0	0.15	900	Yes	Dilution pipettes
10	Specimen-preservation device	25	10	3,600	Yes	Freeze-drying device for tissues; could utilize space vacuum
11	Specimen-storage device	250	70	9,000	Yes	Storage for selected tissues

Table 2-20 (Page 2 of 2)

No.	Equipment Nomenclature	Power (W)	Weight (lb)	Volume (cu in.)	Gravity Dependent	Remarks
12	Monkey exercise device	0	4.5	0	No	Volume included in cages
13	Rat exercise device	0	1.5	0	No	Volume included in cages
14	Video camera (TV)	75	3.0	1,700	No	
15	Movie camera	0.5	3	250	No	Battery-operated, self-contained, includes film; time-lapse desirable
16	Polaroid camera	0	3	110	No	Includes film
17	Timer	0	0.25	5	No	
18	Refrigerated centrifuge	250	4	570	No	Not gravity-dependent if Douglas centrifuge tube is used.
19	50-100 X Lens	0	0.1	5	No	Hand-held
20	Impact Sled	0	3	900	No	For rodents only; spring-loaded
21	Fracture-Treatment Kit	0	7	900	No	Includes fracture reduction and fixation devices and fracture inflictor
22	Shock-Treatment Kit	0	3	200	No	
23	Burn-Treatment Kit	0	3	200	No	Includes burn inflictor
24	Cut-Treatment Kit	0	3	200	No	Includes cut inflictor
25	Contusion-Treatment Kit	0	3	200	No	Includes contusion inflictor
26	Radiation-Treatment Kit	0	3	200	No	
27	Pulmonary-Irritation Treatment Kit	0	3	200	No	Includes pulmonary-irritation inflictor
28	Infection-Treatment Kit	0	3	200	No	

3. Muscle Strength--If it proves feasible to train animals in a simple motor task such as exerting force against an instrumented surface, an indication of muscle strength can be periodically provided.
4. Temperature--The temperature may be determined as required with a quick-acting thermocouple or thermistor.

2.4.3 Experiment Housekeeping Equipment

Currently foreseen requirements include the following:

1. Portable vacuum cleaner, for cleaning waste traps.
2. Lint-free cloths, for wiping up spills.
3. Soap/disinfectant solution, for cleaning surgical area and cleaning up any other spills.

2.4.4 Personal Equipment

The following potential, personal-equipment needs, in the category of protective clothing, are unique to the animal laboratory facility.

1. Coverall to be used during cleaning of waste traps.
2. Heavy gloves to protect against bites in handling animals.
3. Lead apron and gloves for protection when using X-ray.

2.5 BIOSCIENCE EXPERIMENT OPPORTUNITIES

As pointed out in Section 2.2, the preparation of the experiment program for the animal research facility was based on the need for mission-oriented information. Brief consideration was given in the study to the extent to which the applied animal research facility could be used to conduct basic research. Two categories of basic research were considered: experiments which use the animal subjects provided for the applied research program, and experiments involving other subjects but using the existing facilities. In order that equipment commonalities may be exploited to the fullest extent, it is recommended that applied animal research and bioscience experiment programs be prepared concurrently.

2.5.1 Bioscience Experiments Using Animal Subjects

Rodents, primates, and miniature swine have been recommended as suitable subjects for the applied animal research experiments described in this

report. Bioscience experiments using these subjects could be conducted, either on the same animals, or, on additional animals of the same type, housed in the same facility. Typical of the types of investigations which could be conducted is the effect of prolonged weightlessness on growth, aging, and longevity, and circadian and other biorythms.

2.5.2 Bioscience Experiments Using Existing Facilities

The general laboratory equipment required by the animal research program could be used by a bioscience experiment program. Taking advantage of equipment commonality increases the total effectiveness of the facility. Experiments requiring closely controlled atmosphere could make use of the animal environmental control system if their requirements were compatible.

Typical of the experiment areas which might make use of existing facilities are genetics, plant studies, and basic microbiology. Depending upon the specific experiments chosen, additional items of equipment (for example, culture chambers, perfusion chambers) may be required; however, with few exceptions (for example, electron microscope), these additions could be easily accommodated.

Section 3
CREW TASKS

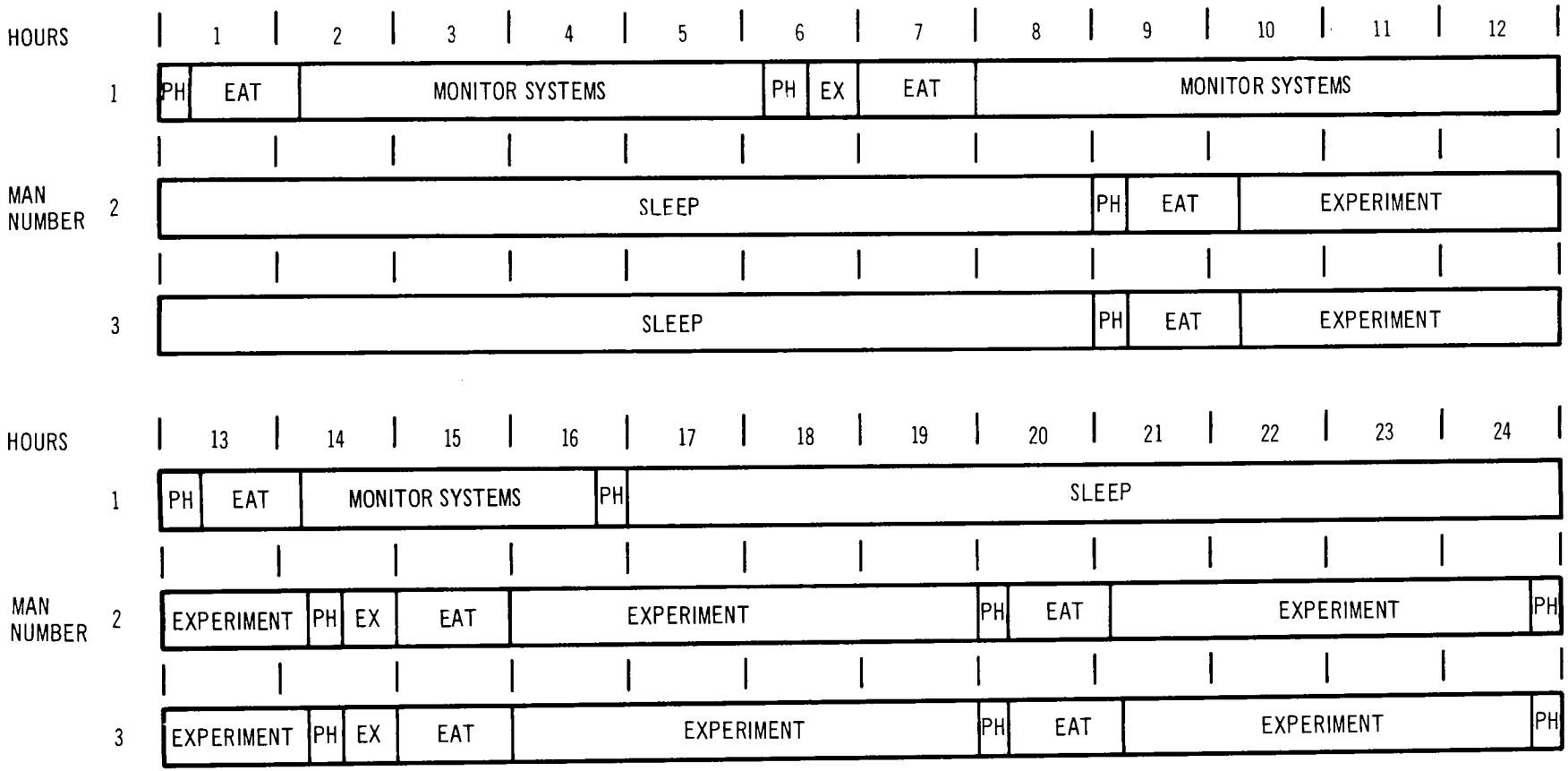
This section of the study examines the nature of the crew tasks associated with an animal research facility and the time available to perform them. It has been determined that the experiment program outlined for an advanced workshop or EOSS mission will consume the majority of the available time of one crew member and about one-third that of a second crew member. As pointed out in the discussion, the time required will be a function of the scope of the experiment program and the degree of automation available at the time.

3.1 DUTY CYCLES

This section contains illustrative duty cycles based upon current NASA and Douglas data. Figure 3-1 shows a candidate duty cycle for a spent-stage workshop mission. This cycle is based on the following assumptions:

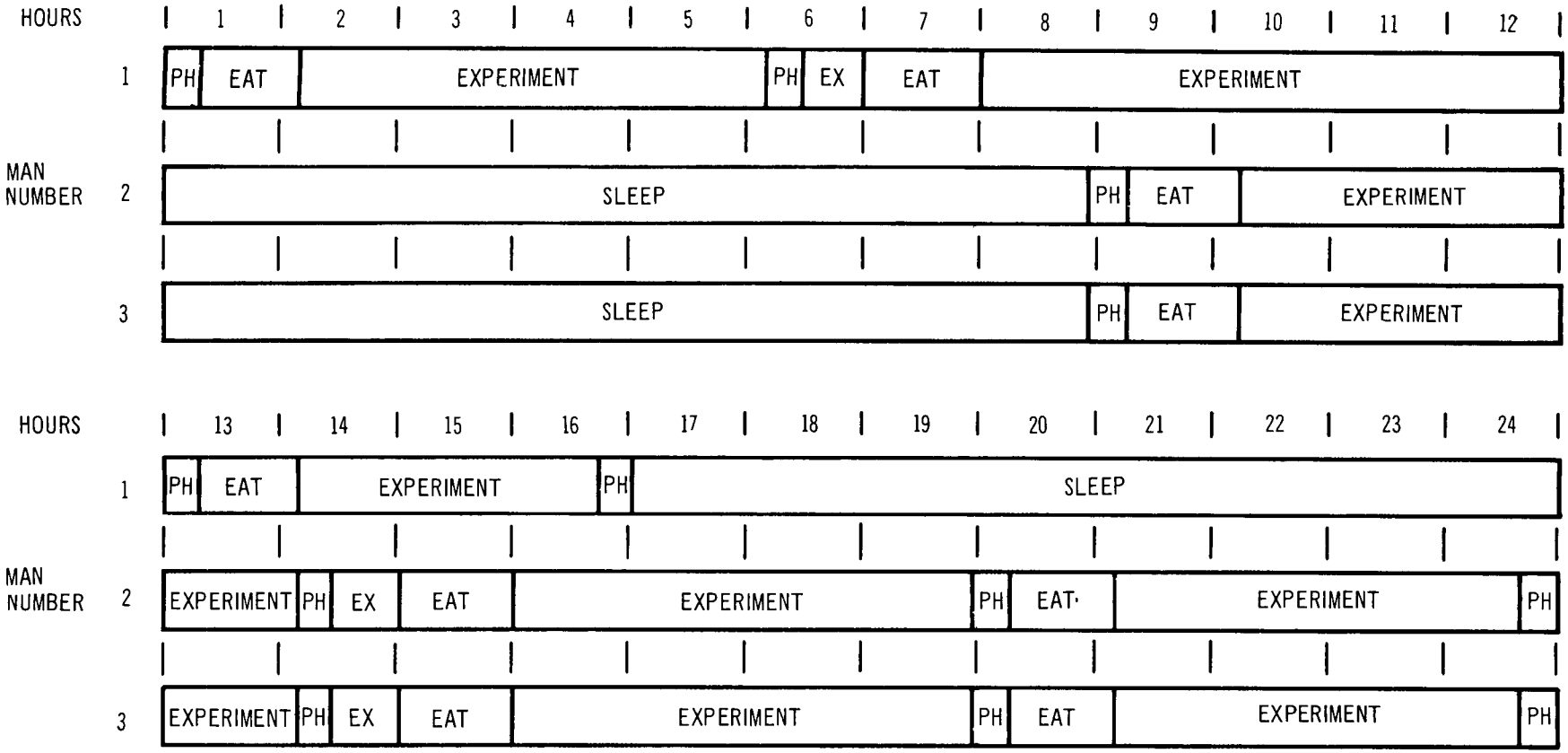
1. An 8-hour sleeping period is allocated to each crewman each day.
2. Three 1-hour eating periods per day are provided for each crewman.
3. The CSM is continuously manned, but the crewman may sleep while manning the CSM.
4. Each crewman is on a nominal 16/8, work/rest cycle.
5. One 30-min. exercise period per day is allocated for each crewman.
6. Four personal hygiene periods of 15 min. each per day are allotted for each crewman.
7. Exchanges of duty schedules among crew members may be arranged to relieve monotony.

Figure 3-2 shows a candidate duty cycle for an EOSS mission. The major difference between this and the preceding figure is based on the assumption that an Apollo standby mode is available for advanced systems so that the CSM need not be continuously manned.



EX, EXERCISE; PH, PERSONAL HYGIENE

Figure 3-1. Duty Cycle – Spent-Stage Mission



EX, EXERCISE; PH, PERSONAL HYGIENE

Figure 3-2. Duty Cycle – EOSS Mission

3.2 INSTALLATION TASKS

3.2.1 Spent Stage

Typical installation tasks will involve transport of components, installation of components using fasteners and tie-downs, adjustment of centrifuge structure, rigging of covers over centrifuge housing and over animal cages, hooking up of wiring and ducting, installation of seals, and lubrication of mechanisms. Although time-consuming, these tasks do not require high skill levels or unique types of knowledge. System familiarization and adequate simulation and training before flight should provide astronauts with required capability. One area requiring additional study is the providing of appropriate mobility aids to ensure that all areas of the tank interior can be reached in the accomplishment of specific tasks. A potential sequence of operations is shown below. This sequence would begin after the airlock is activated and the spent stage is pressurized.

1. Transport remaining supplies and components into the spent stage.
2. Install additional personnel restraints.
3. Rig cargo transport lines.
4. Install additional lighting.
5. Install ECS modules (LiCl, LiOH, fans).
6. Hook up wiring, ducting, and water supply.
7. Install covers on cages.
8. Install filters in cages.
9. Bring animal transport module into tank.
10. Activate ECS.
11. Transfer subjects.
12. Install food supply for animal cages.
13. Fasten centrifuge structure to common bulkhead.
14. Install centrifuge motor and drive unit.
15. Adjust centrifuge supports.
16. Install seals in drain openings of ECS ducts and centrifuge structure.
17. Lubricate drive mechanism.
18. Install partition over centrifuge housing.
19. Install exercise devices.

20. Set up experiment apparatus and biomedical monitoring equipment.
21. Start up centrifuge.
22. Begin experiment operations.

Total time to accomplish these tasks is estimated at 27 man-hours

3.2.2 EOSS Configuration

The majority of the above functions would not be required for the EOSS configuration. Except for minor adjustments and inspection, the majority of tasks would consist of activation of subsystems and monitoring of system operation.

Total time to accomplish these tasks is estimated at 9 man-hours.

3.3 EXPERIMENT TASKS

3.3.1 General Experiment Tasks

Experiment task groupings will be differentiated primarily by mission duration. For a single-launch mission without resupply, crew tasks will involve care of animals and rather simple experiments. With long-duration missions (up to a year or more), the range of crew functions will be dependent upon the variety of equipment which can be supplied and the complexity of the experiment program. If all desired scientific equipment can be provided, the complexity of detailed tasks will be dependent upon design of the equipment and methods used in conducting experiments. The following are representative crew functions for a complex experiment program for a long-duration mission:

1. Review experiment log and schedule.
2. Review experiment handbook.
3. Inspect food and water supply.
4. Inspect animal subjects.
5. Perform conditioning experiments. Representative tasks include placing subject in exercise device, activation and monitoring, and data recording.
6. Perform medical experiments. Representative tasks include subject preparation (cleaning of surgical area, restraining, and draping subject), performing surgical procedures, administering therapeutic treatment, and recording observations.

7. Collect biological samples and perform laboratory tests. Representative tasks include collection of blood, urine, and tissue specimens and performing related laboratory analyses and microscope studies.
8. Preserve and store specimens. This includes quick freezing and storage of subjects for subsequent study on the ground and preservation of any required fluid and tissue specimens.
9. Experiment Support Tasks. These are intermittent tasks which include determination of subject weight (mass), measuring muscle size/strength, and replenishment of food supply.

Crew-activity studies to date indicate that crew work load would be low on a short-duration, single-launch mission unless most tasks were performed in a manual mode. Work load for long-duration missions tends to be high because of wider variety and greater complexity of crew functions and greater number of animal subjects. An extensive degree of automation of functions is necessary, but with sufficient manual backup to ensure accomplishment of major experiment program objectives. Specific work-load estimates will remain gross until more experiment and equipment-design details are formulated.

When a considerable portion of the work load is repetitious but requires manual accomplishment (such as laboratory analyses), adequate work aids such as equipment holders and stowage provisions should be provided. It may prove most desirable to develop a fixed work station for laboratory studies. This could be a console-and-chair arrangement and might be located near the centrifuge controls and system-monitoring displays.

3.3.2 Crew Experiments

The early MOARF missions will have no crew experiments as such. However, biomedical monitoring data on the crew should be collected on specific physiological conditions throughout the mission. The Integrated Medical Behavioral Laboratory Measurement System (IMBLMS) currently under development by NASA, could be advantageously applied in this area. These measurements might be considered experiments because the missions will provide opportunities to gather crew physiological-deconditioning data for a period of 30 days or longer. These data may be directly correlated with the animal data to facilitate the generalized application of the animal data to humans.

Unique opportunities for gathering crew data also should be exploited. Examples of such data include unique behavioral requirements involved in

conducting the experiment program and the healing characteristics of any injuries received by the crew during the mission.

3. 3. 3 Hardware Experiments

Animals are required for testing the feasibility of orbital parachute/space escape devices such as the foam capsule suggested by General Electric and the cone concept proposed by Douglas. Such experiments are not a part of this study, but this concept should be considered as an auxiliary activity.

3. 4 HOUSEKEEPING TASKS

Animal-cage waste traps should be cleaned periodically to reduce the possibility of contaminating the animal-housing atmosphere with particulate matter and to prevent the reduction of air circulation through the cages. The waste traps may be cleaned with a portable vacuum cleaner. Collected wastes may either be processed in the waste management system, stored, or dumped overboard.

The facility and its equipment should be cleansed as required. Sponges wetted with soap solution may be used for cleansing soiled or stained surfaces. Damp surfaces may be dried using a dry sponge or cloth. Particulate matter can be removed with a portable vacuum cleaner . Such dry waste as scrap paper may either be processed in the waste-management system, stored, or dumped overboard.

3. 5 TIMELINE ANALYSES

A rough draft of a mission timeline was prepared early in the study. This was based upon earlier spent-stage studies and includes crew tasks associated with stage activation. Since then, additional task data have been generated for equipment installation and performance of experiments. This information has been used to check potential crew work loads and to identify design requirements as conceptual design has progressed. Candidate timelines for a spent-stage mission and for a prelaunch modified-stage mission are shown in Figures 3-3 and 3-4.

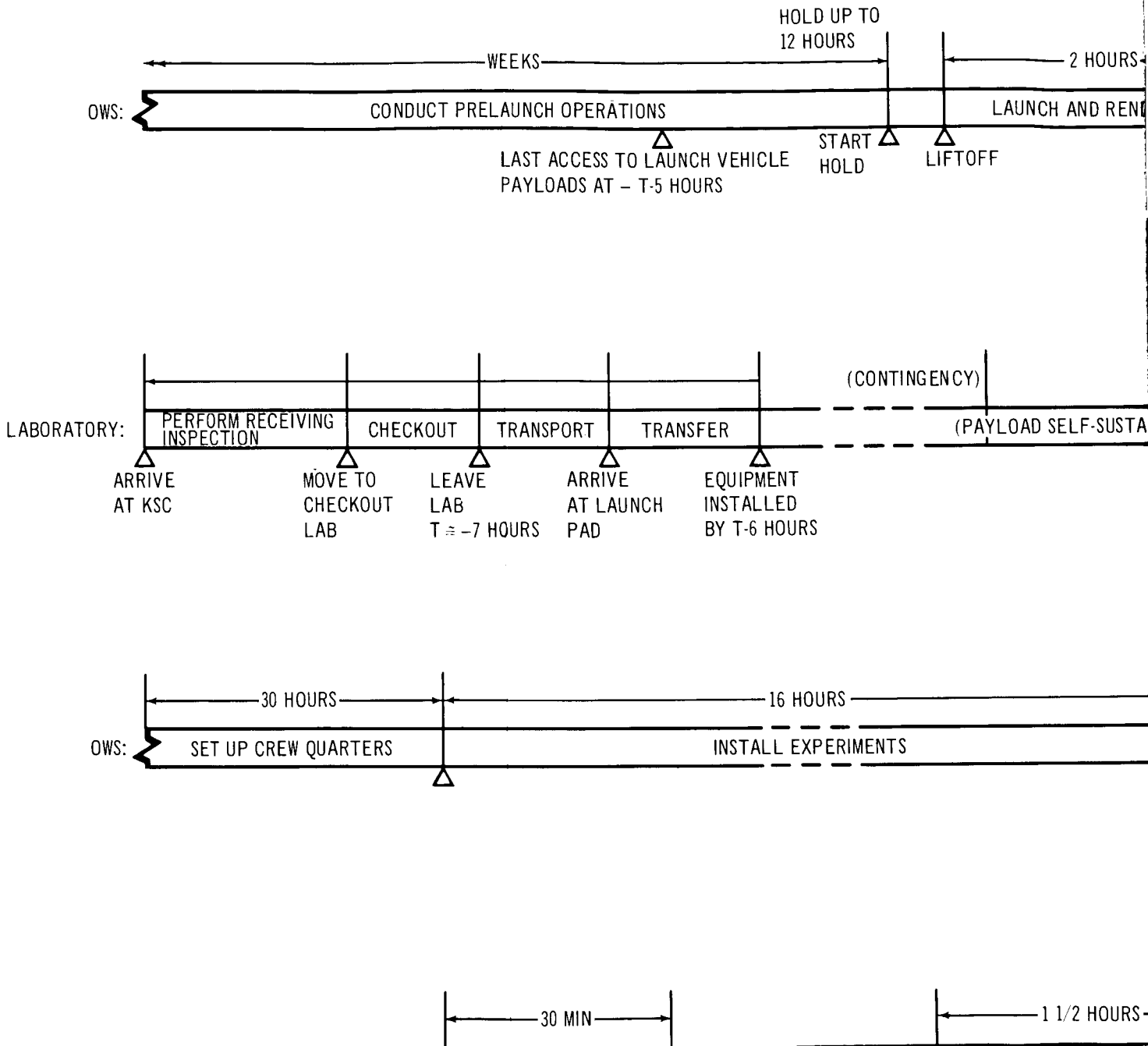


Figure 3-3. Timeline Analysis – Spent Stage (Orbital Workshop)

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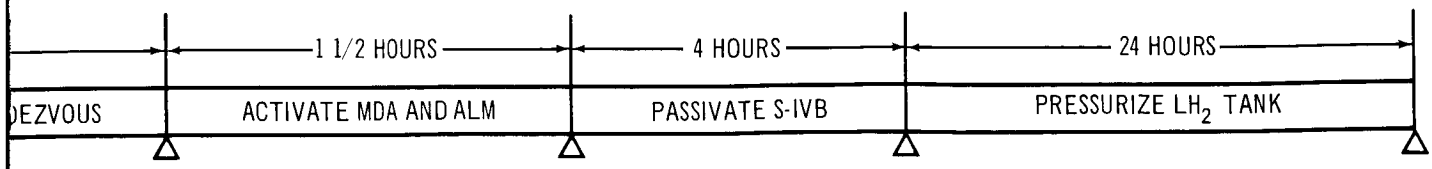

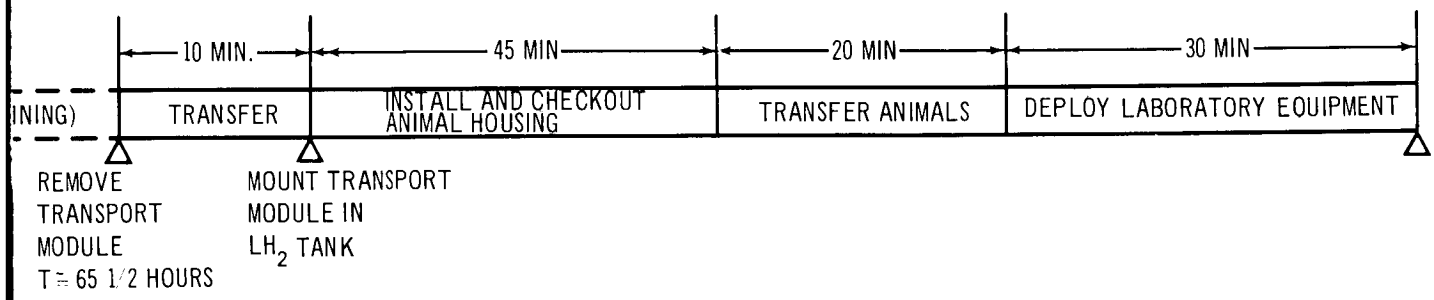

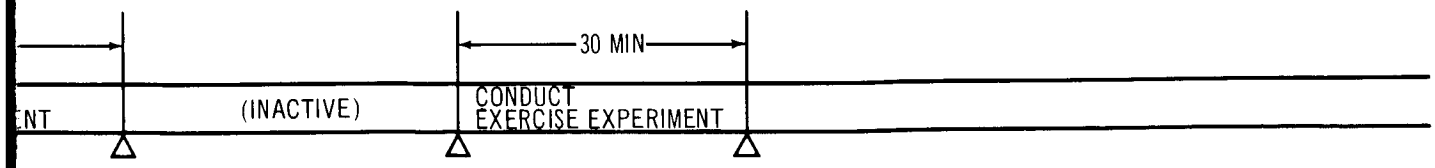

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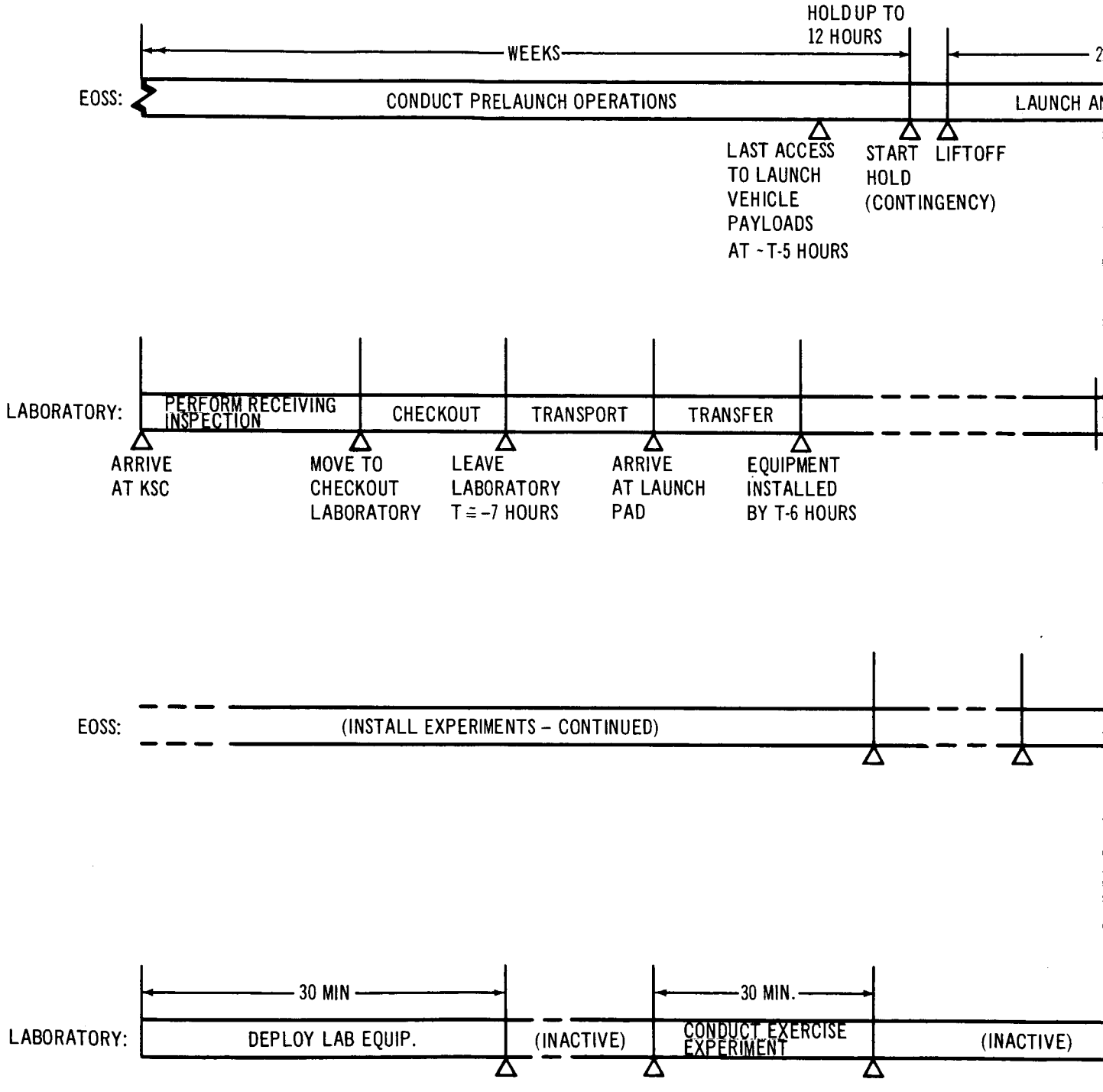

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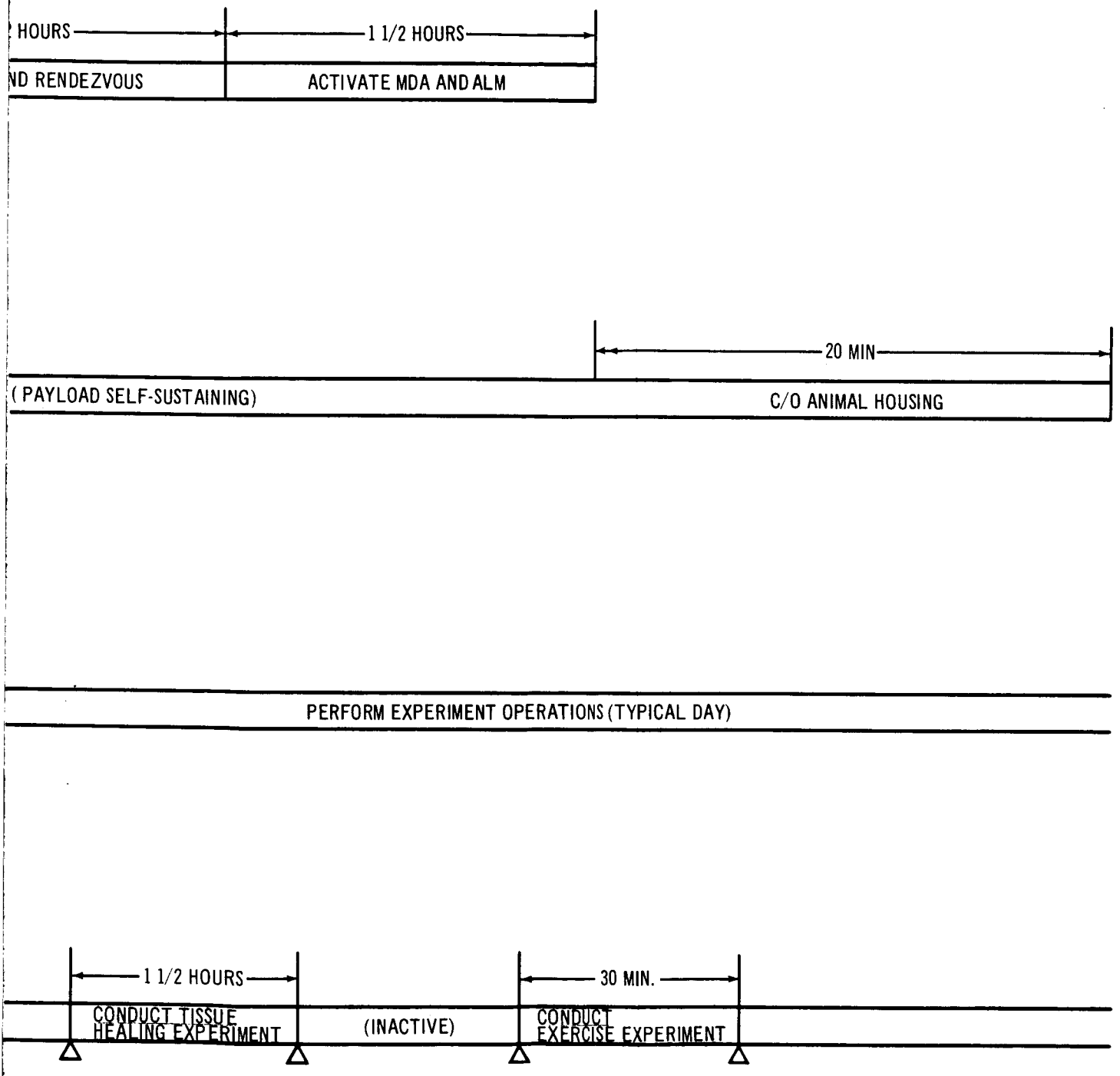

Figure 3-4. Timeline Analysis – Prelaunch Modified Stage (EOSS)

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3.6 MAN/SYSTEM INTEGRATION

3.6.1 Biomedical Requirements

Routine biomedical monitoring provisions will undoubtedly be utilized on orbital-workshop missions. In addition to these provisions and because of the presence of the animal colony, other precautions should be taken to ensure the health of the astronauts. Microbiological studies could be performed on cultures of material from animal cages to detect buildup of harmful bacteria or fungi. First-aid supplies should include appropriate materials for treating animal bites and scratches. The atmosphere in the cages should be monitored to detect the buildup of toxic or noxious substances.

3.6.2 Experimenter Selection and Training

A preliminary functional analysis of the baseline facility and the experimental program has been conducted to derive crew-skill requirements for a three-man crew. The analysis indicates that one engineer from the astronaut pool would be required to manage facility operations, maintenance, and facility setup in orbit. Two scientist-astronauts with appropriate laboratory experience should fill the two remaining positions. The experimenters should be of age and health status comparable to today's astronauts.

The scientist-astronauts should be intimately familiar with experiment techniques and with the handling of experimental laboratory animals. It would be desirable that their backgrounds include degrees in both experimental physiology and veterinary medicine. Professionally trained personnel are recommended for the positions of experimenters because they will be responsible for conducting scientific experiments requiring extensive knowledge of experimental procedures and techniques. These individuals must be able to solve scheduled and unscheduled problems, to make decisions relevant to the experimental program, and to interpret experiment data. Professional specialists not only would be better qualified to conduct the experiments, but also would reduce training costs because these skills are more easily selected than trained.

The 9-phase, 1-year mission training program that follows is recommended:

1. Mission and total system familiarization.
2. Subsystem familiarization.
3. Components familiarization.
4. Duty position.
5. Personal maintenance.
6. Special procedures.
7. Emergency procedures and safety.
8. Experiment program.
9. Experiment techniques in the orbital environment.

3.6.3 Candidate Trade Studies

Trade studies should be refined as animal research facility systems evolve and as related mission functions become more firmly defined. A major area involves tradeoffs between manual and automatic methods of performing various functions. Such simple or routine tasks as feeding and monitoring subjects should be automated; more-complex and less-structured tasks, such as inspection of subjects for signs of injury or illness, basically would remain manual tasks with the employment of supporting diagnostic equipment.

Methods of exercising animals and recording energy expenditure require further study.

Provisions for avoiding cross-contamination of subjects and crew require additional refinement as design progresses.

Section 4
MISSION DEFINITION AND ANALYSIS

During the early portion of this study, NASA had not published plans for orbiting missions using spent S-IVB and S-IVB prelaunch-modified stages. In order to study the resources available for the applied animal research experiment programs, several candidate mission configurations were analyzed. They consisted of a short-term single-launch workshop, a short- and long-term dual-launch workshop on the Saturn IB vehicle, and a prelaunch modified S-IVB on a Saturn V vehicle. These missions were described in the midterm report of this study. A summary of the description is included in this section. Experiment programs suitable for these missions are described in Section 2. Full advantage was taken of all of the resources available in these missions without regard to the requirements of other experiment programs since, except for behavioral experiments involving the crew, no other program descriptions were available.

Since that time, and in the latter portions of the study, specific mission definitions have been published by NASA, and experiment programs have been defined for the first workshop mission. Experiment programs for later missions, including the early orbiting space station (EOSS) version of the prelaunch-modified or dry-launch S-IVB, are being studied by NASA contractors.

The most dramatic limitation, and an understandable one, which the new plans have on the candidate applied animal research experiment programs is the necessity to share available resources with other disciplines. All of the spent-stage, workshop-type missions are severly payload limited, and this will cause active competition for the available weight. However, since the purpose of this study was to investigate the feasibility of performing candidate animal experiments in these types of missions and not to prepare development plans, these limitations do not degrade the results of the study.

4. 1 MISSION REQUIREMENTS

The basic requirement imposed on the mission by the animal experiment program is that it provide a weightless environment for periods of time up to 1 year. As fundamental as this requirement may appear, it is subject to compromise in both areas. (See Section 4. 3.)

The experiment programs described in Section 2 were designed to conform with the experiment payload weight and volume capabilities of the missions described in Section 4. 2. As pointed out in Section 4, the workshop mission programming now underway in NASA will constrain the experiment design to the available payload weight and volume. EOSS's launched on a Saturn V vehicle are volume limited and not payload-weight limited. The animal research facility weight and volume requirements are as follows:

Short-term workshop (30 days)	1, 300 lb	125 cu ft
Long-term workshop (60 days)	2, 000 lb	875 cu ft
EOSS (365 days)	47, 000 lb	2, 200 cu ft

The animal experiment programs described are not sensitive to orbital inclination or altitude. Inherent in the altitude, however, is the orbital lifetime of the vehicle. The results of an analysis performed by Douglas on another contract show that an S-IVB workshop within initial orbital altitude of approximately 240 nmi (480 km) will have an orbital lifetime in excess of 1, 000 days without the need for orbit-keeping propulsion. (See Figure 4-1.) This altitude is therefore recommended for missions which include animal research activities.

Requirements for the protection of the animal subjects from the radiation environment are the same as those for the astronauts in the same environment; therefore, no special requirements exist. Should a solar-flare event occur, it is conceivable that the animals would receive radiation doses which would affect the experiment results. Radiation monitors should be provided for this eventuality.

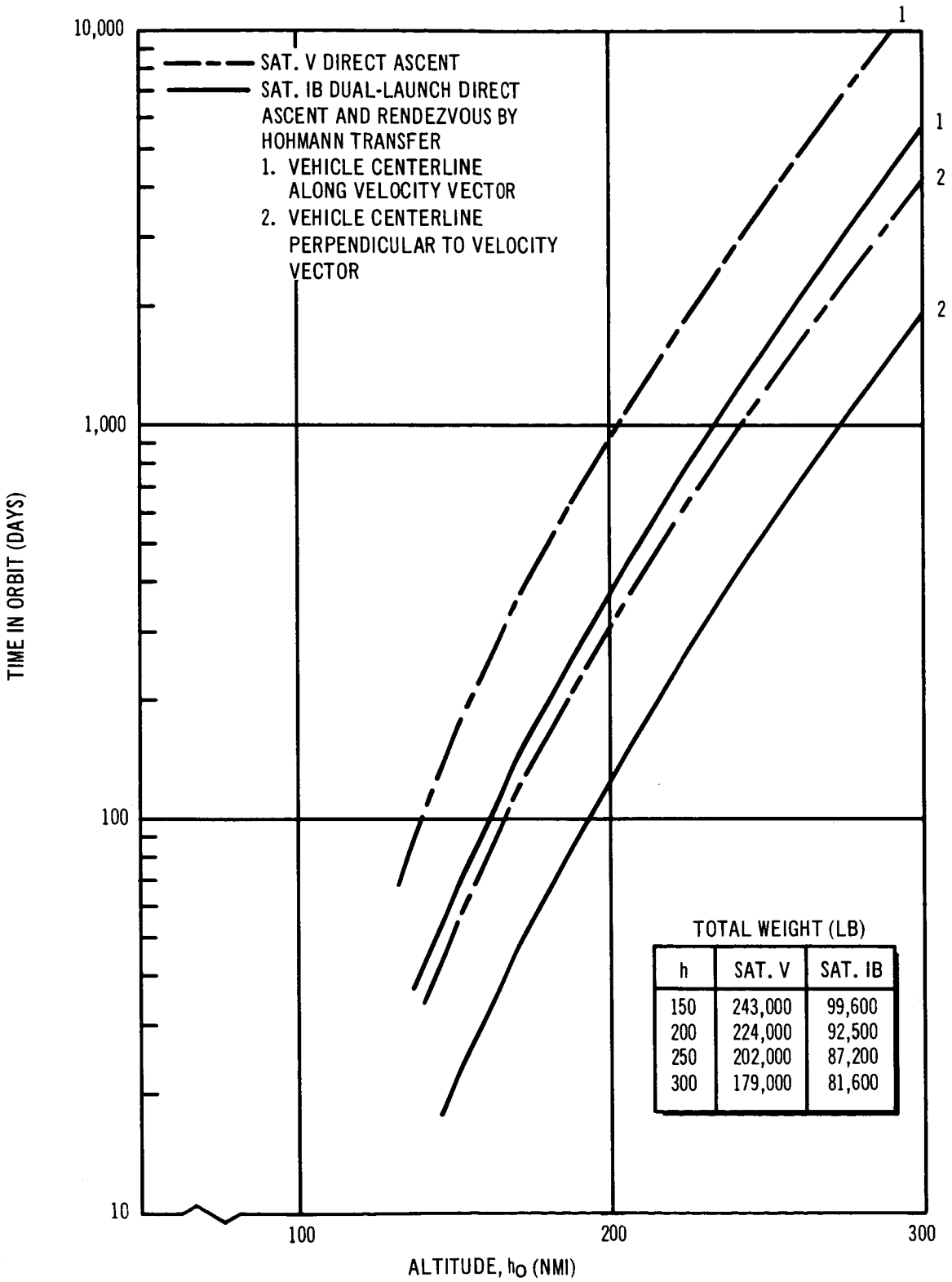

Figure 4–1. Circular Orbit Life Times

4.2 REPRESENTATIVE MISSIONS STUDIED

The four mission configurations which were used to size the experiment programs are described in Table 4-1. The first two, although capable of orbital lifetimes of 50 days, were limited to a useful lifetime of 30 days by the airlock module capacity. For that reason, a minimal animal experiment program was described. Although the useful lifetime could be extended by a resupply flight, additional propulsion subsystems would be required for orbit keeping if the lifetime were to be extended beyond 50 days. This would effectively remove any experiment payload capability. The third mission described is not unlike the current NASA plans for the first workshop mission. The major difference is the absence of the weight of the multiple docking adapter in the payload calculations. This concept was not being considered at the time the analysis was done. This type of mission is capable of supporting the long-term experiment program. It was assumed that the workshop would be continuously manned for a year.

The fourth mission described is the prelaunch modified S-IVB (EOSS). In this configuration, the S-IVB is ground equipped as a laboratory and placed in orbit with a manned CSM by an S-IC and S-II combination. The S-IVB would not have a booster function, although the vehicle would be assembled and launched in a Saturn V configuration. This version has more than adequate lifetime and payload capabilities and provides the facility for performing the same long-term experiment program that was described for the third workshop-type mission. However, since the laboratory would be installed and equipped on the ground, more extensive facilities could be provided than would be possible in a laboratory that required setup in orbit.

4.3 NASA-PLANNED MISSIONS

A brief description of S-IVB workshop and EOSS missions currently planned or being studied by NASA, is provided in this section to give the reader an opportunity to relate the general requirements of applied animal research programs to the resources which are likely to be available. Official NASA documents should be studied for complete information.

Tab

SUMMARY OF CA

Description	Vehicle Configuration*	Altitude	Incl
Single-launch workshop without resupply	Saturn IB with AM and CSM	175 nmi (320 km)	
Single-launch workshop with resupply	Saturn IB with AM and CSM	175 nmi (320 km)	
	Saturn IB with RM and CSM	175 nmi (320 km)	
Dual-launch workshop with resupply	Saturn IB with CSM	260 nmi (480 km)	
	Saturn IB with AM and nose cone	260 nmi (480 km)	
	Saturn IB with RM and CSM	260 nmi (480 km)	
EOSS (prelaunch-modified S-IVB)	Saturn V with EOSS and CSM (no propulsive S-IVB)	260 nmi (480 km)	

*AM--Airlock Module; CSM--Command and Service Module; RM--Resupply Module;
**Re-entry is imminent after this time.

ble 4-1

NDIDATE MISSIONS

ination	Orbital Lifetime**	Gross Weight in Orbit	Experiment Payload	Remarks
28.3°	50 days	66,200 lb (30,000 kg)	1,822 lb (830 kg)	Facility activated in orbit by crew. Mission terminates at expiration of AM subsystems.
28.3°	50 days	66,200 lb (30,000 kg)	1,822 lb (830 kg)	Facility activated in orbit by crew. Orbital lifetime extended with propulsion subsystem support.
28.3°		33,300 lb (15,100 kg)	4,400 lb (2,000 kg)	Crew with RM replaces original crew.
28.3°		31,900 lb (14,740 kg)	9,700 lb (4,400 kg)	Crew on first launch performs scientific mission prior to S-IVB workshop launch.
28.3°	600 days	53,400 lb (24,220 kg)	9,412 lb (4,270 kg)	Crew rendezvous CSM with AM/ S-IVB workshop and activates facility.
28.3°		31,900 lb (14,740 kg)	3,000 lb (1,360 kg)	Orbital altitude maintained with propulsive subsystem support.
28.3°	4,000 days	200,000 lb (90,600 kg)	90,000 lb (40,750 kg)	Ground-equipped EOSS is activated by the crew on arrival at orbit.

EOSS--Early Orbiting Space Station.

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4. 3. 1 Spent-Stage or Workshop Missions

Two missions of this type are planned. They are known as Cluster A and AWS-LO-B (Advanced Workshop--Low Orbit B). The first one is scheduled for flight in 1969 and the second in 1970. Except for the AAP experiment payloads carried, the configurations of the missions are essentially the same.

The mission begins with the launch of a manned CSM. Following a period of 3 or 4 days, a second launch places the unmanned workshop in orbit. The workshop consists of an S-IVB (after it has performed its propulsive function) with an airlock module (AM) and a multiple docking adapter (MDA) attached. The crew in the CSM, already in orbit, will rendezvous and dock with the spent-stage workshop and activate it. After carrying out orbital experiments for approximately 28 days, the crew will place the workshop into a storage condition and return to Earth using their CSM.

All of the experiment equipment is carried into orbit on the workshop launch and is stored external to the S-IVB fuel tank, either in the AM and MDA or in the S-IVB forward skirt area. It must be transferred into the fuel tank workshop and set-up prior to doing the experiments.

Plans call for the orbiting workshop to be revisited approximately 3 months after the first crew returns. The launch which carries this crew to the workshop will carry additional experiments and supplies to activate the workshop for a 56 day period. Crew exchange and resupply may occur at this time.

During the "storage" period, experiments in separate self-sufficient capsules (such as the orbiting primate experiment and in configurations which can be docked to the workshop complex) could remain with the workshop. Observations on experiment subjects in the capsule would be made by the astronauts during their scheduled revisitation of the workshop.

The AWS-LO-B mission may be continuously manned for at least a year after being placed in orbit with the same routine described above.

As pointed out previously in this study, workshop missions are payload limited. For example, the workshop launch, after allowance is made for life-support requirements, may carry approximately 1, 500 lb of experiment equipment. Limited amounts of additional equipment could be carried on resupply missions.

4. 3. 2 Ground-Equipped EOSS Missions

This type of mission is the same as described in Section 4. 2. Current plans call for it to fly in the 1971 to 1972 time period.

4. 4 UTILIZATION OF SEPARATE MODULES

Several aspects of the animal research facility program warranted the consideration of using modules which could be isolated from the workshop or space station, but still be attended to by the crew.

An artificial-gravity mode of operation of the workshop for limited periods of the mission has been studied by NASA as an experiment. If this plan is adapted, the zero-g requirement of the program would not be met. It would therefore be necessary to house the experiments in a separate module which would not be affected by the artificial gravity. Alternately, the animal experiments would have to be completed before or performed after the artificial-gravity experiment. Of course, if artificial gravity became a way of life for space stations, the zero-g environment requirement for animal experiments would be replaced by a partial-g requirement.

The atmosphere currently planned for workshop and EOSS configurations is a two-gas type (O_2 and N_2) at from 5 to 7 psi. This reduced pressure is considered by some in the biology community as intolerable because all of the control information available has been obtained on animals in an Earth atmosphere, and the change in atmosphere would cloud the results of experiments which were investigating the effects of weightlessness only. Maintaining a colony of animals at 14. 7 psi inside a space station at 7 psi presents severe problems in equipment design, handling techniques, and contamination. A separate module maintained at 14. 7 psi would resolve these problems.

Contamination of the space-station atmosphere by the animal colony atmosphere is a potential hazard. In general, this problem can be taken care of by adequate sealing methods in the design of the housing and by operating the colony at a pressure slightly less than that of the space station. Using a separate module with an isolated environmental control system would effectively eliminate this problem.

Two items of Apollo hardware are available for use as separate experiment modules, the ascent stage of the lunar excursion module (LEM) and the refurbished command module (RCM). Another module currently being studied by NASA is the basic subsystems module (BSM) or powerhouse. The suitability of these modules to house an animal experiment program has been studied and is described in Section 5.

4.5 MISSION PLANNING

In addition to the equipment and experiment design activity which must take place prior to performing extensive animal experiments in orbiting missions, several other factors must be considered when planning the missions.

Arrangement must be made for a facility to maintain the control groups described in Section 2 of this report. The candidate flight animals would come from the same facility. Colonies of animals would be raised in this facility in an environment which, with the exception of weightlessness, duplicates the space station environment. Historical data gathered from these colonies will be required in the analysis and evaluation of the data obtained in space.

At the launch site, facilities must be provided to house those animals selected for flight and as many alternates as deemed necessary by the experimenter. A controlled atmosphere must be supplied to the animals prior to launch after they are installed in the launch vehicle to avoid using on-board consummables.

When samples and/or animal subjects (alive or sacrificed) are returned to Earth for examination, special provisions must be made on the recovery ship to handle this material without destroying its value. This may require transportation by air from the ship to the Earth laboratory. Alternately, it may be more convenient to provide facilities on-board the ship to permit examination of the samples.

Throughout the mission, specialists in the orbiting experiments should be on call to supply advice to the crew when difficulties or unforeseen events occur.

Since the requirements discussed above are all governed in detail by the experiment program to be performed, it is necessary that the program be established as early as possible. The experiment programs defined and studied in this report are recommended as a baseline for mission planning.

Section 5
ANIMAL FACILITY INSTALLATIONS

The support requirements of the experiment programs prepared in this study were analyzed and translated into equipment requirements and design concepts of laboratory facilities suitable for installation in the spent Saturn S-IVB workshop, and the S-IVB ground-equipped early orbiting space station (EOSS). The environment control and life support (EC/LS) system for the animals is the most prominent part of the facility and emphasis was placed on this in the study. The other support requirements of the animal experiment program are not unique and therefore, impose loads on the existing support subsystems.

In Section 4, the possible requirement for an isolated animal facility was discussed. The extent to which separate modules could be employed for this purpose is described in this section.

5.1 ANIMAL RESEARCH FACILITIES IN THE S-IVB WORKSHOP

Subsystems and facility installations which reflect the requirements of the experiment programs for this type of mission are described in this section. The facilities required by programs which are less ambitious than those upon which these configurations were based may be obtained by the simple process of scaling down.

It has been determined in the study that the major problem associated with utilizing the spent S-IVB is the design of equipment suitable for easy assembly by the crew once orbit has been achieved. This problem can be further alleviated if the designs are such that as much equipment as possible be installed permanently in the S-IVB fuel tank prior to launch. Of course, such equipment must be compatible with the liquid hydrogen fuel and must not compromise the functioning of the S-IVB as a propulsive stage.

5.1.1 Subsystem Requirements and Design Concepts

The design concepts described in this section represent a feasible approach to meeting the experiment requirements and illustrate the extent of the typical demands which would be imposed on a 45-day workshop mission.

5.1.1.1 Animal Subject EC/LS Subsystem

The EC/LS system for the animals include all of the subsystems normally found in a semi-closed ecological EC/LS systems in spacecraft for man. The animals eat food, consume oxygen, and generate CO_2, urine, feces, water vapor, heat, and trace contaminants just as man does. The waste management for animals is, however, more difficult, since they cannot be trained to dispose of their waste and the trace contaminants generated by the feces and urine must be removed from the atmosphere or made harmless. Because of waste-management considerations, it seems desirable and perhaps necessary to have a closed-loop EC/LS system which essentially isolates the animal's atmosphere in the cages from the laboratory atmosphere in which the human occupants work. With a closed-loop system, it is only necessary to provide a habitable environment and a life-support system for the animals which is essentially independent of the atmosphere in the laboratory for the humans with respect to humidity, CO_2 concentrations, and trace contaminants. The animal EC/LS systems can be supplied with the consumables required by the animals only, without difficult interfaces with the laboratory EC/LS systems. A schematic diagram of the proposed animal subject EC/LS system is shown in Figure 5-1. It includes subsystems which provide for waste management, ventilation and thermal control, humidity control, CO_2 control, and trace contaminant control. These subsystem are discussed separately later.

Specific Life-Support Requirements for Rats

The following table summarizes life-support and metabolic requirements for adult laboratory rats:

Body Weight (g)	Heat Output (kcal/Day)	O_2 Intake (L/Day @ S. L.)	CO_2 Output (L/Day @ S. L.)	Food Intake (g/Day)	Water Intake (g/Day)
200	30	6	5	10	4

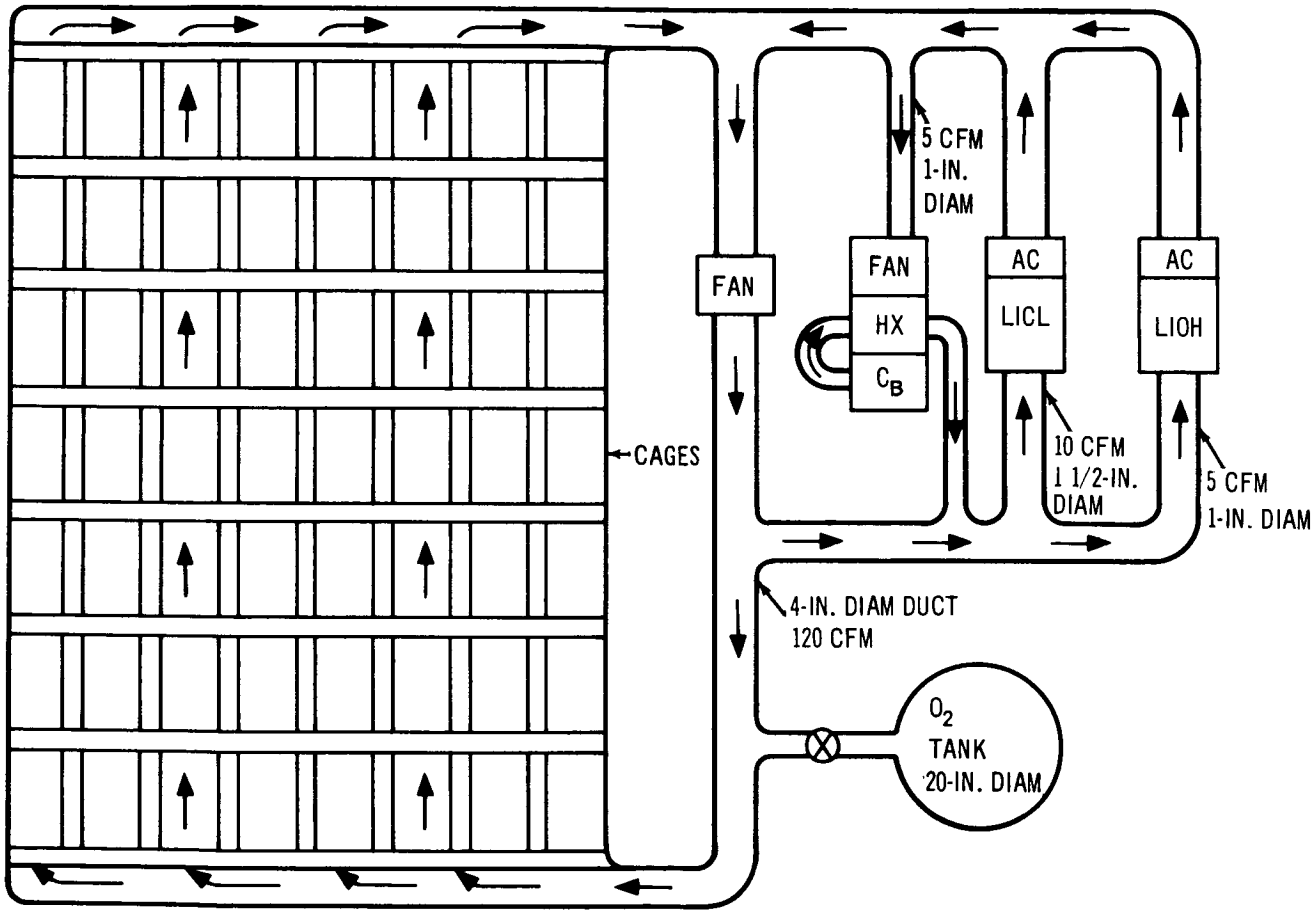


Figure 5-1. Schematic Typical Cage Area Environmental Control System

These animals should be kept in an environment with a temperature between 65° and 85°F and 30% to 70% R.H. A CO_2 partial pressure of zero to 5 mm Hg should be acceptable, and trace contaminant levels should be held to reasonably low values. Bacteria levels should not exceed those that they are normally exposed to in ordinary experimental laboratories. For the purpose of studies on EC/LS requirements, a cage volume of 0.4 cu ft has been used along with an atmosphere of 100% oxygen at 5 psia.

Waste Management

Various schemes for feces and urine removal have been considered for space animal systems. The one which appears best involves utilizing air motion and aerodynamic drag on particulate matter to sweep the air clear and to move the liquid urine and fecal matter to waste pads where it is retained and dried. Since this system will operate in a zero-g environment and offers a relatively simple system, it was selected for use in this study. It was assumed that the animals will soon learn to face upstream when defecating and urinating. An analysis of the aerodynamic drag sweeping characteristics with a 5-psia O_2-ventilating atmosphere indicated that a velocity of approximately 50 fpm would provide adequate acceleration from the cage of particulate matter. This velocity of 50 fpm was selected for sizing cage dimensions. A curve showing the time distance characteristics of the aerodynamic drag sweeping scheme is shown in Figure 5-2. It should be noted that this same drag effect will slowly move the animal to the downstream end of the cage if it should let go of the screen walls of the cage. In effect, it provides a very small gravity in the direction of the waste pads. Other studies indicate that the waste pads should be capable of retaining a 45 days or more output of fecal matter without attention. The humidity-control system will be designed to maintain a relatively dry, 30% relative humidity, atmosphere in the cages so that the fecal matter will dry without excessive decomposition. However, provisions are made for replacement or cleaning with the use of a small portable vacuum cleaner if necessary. In the case of urine, the pads are intended to hold liquid urine until it evaporates and is removed by the LiCl desiccant in the humidity-control system. The waste pads are installed outside of the downstream screen of the cages with a mesh size large enough to pass the largest particles. This will prevent the animal from contacting the waste after being collected by the pad.

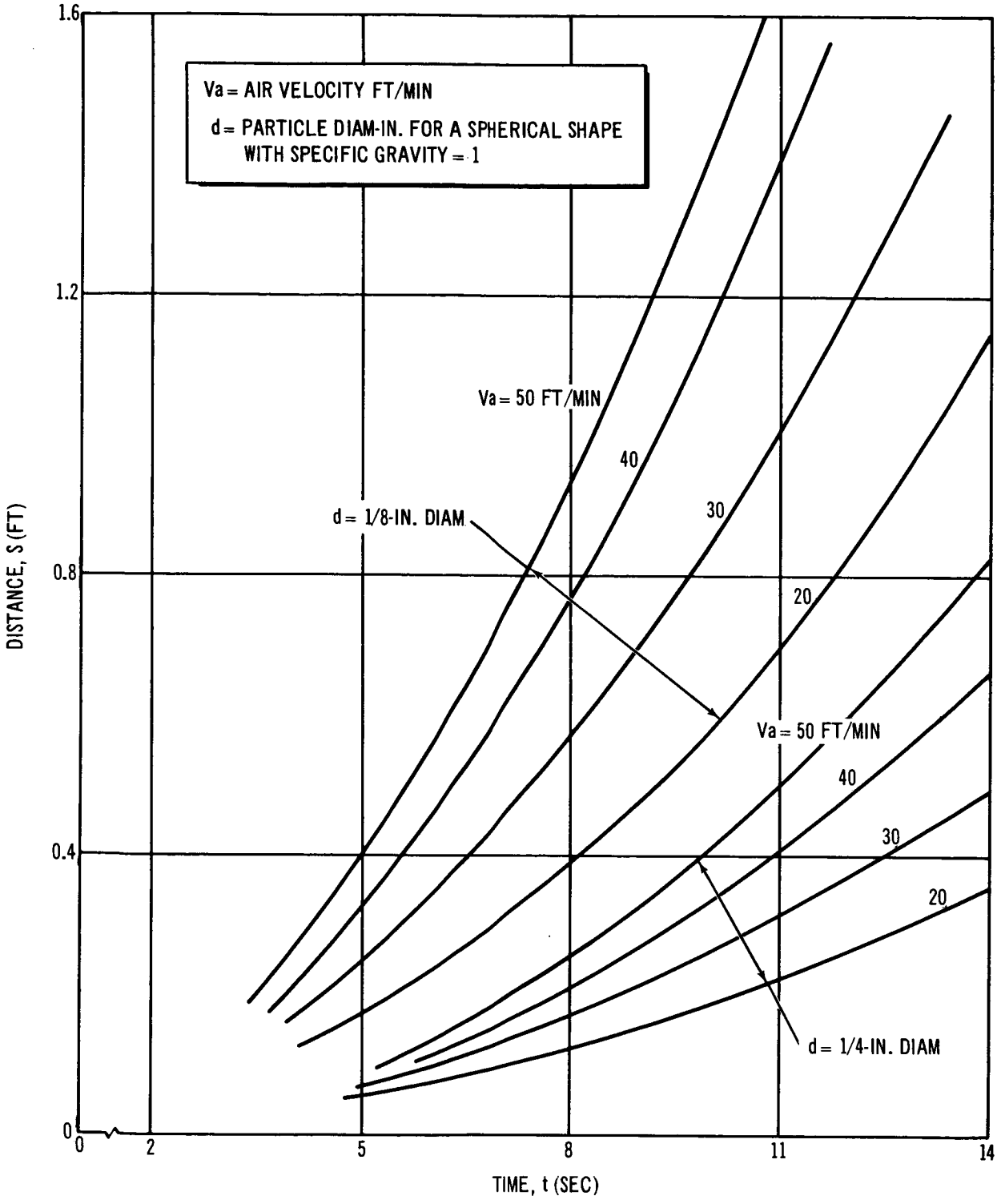


Figure 5-2. Distance as a Function of Time for a Particle to Move Under Aerodynamic Drag

The penalty for moving a volume of air is fan power. If the air velocity is fixed as above, then the air volume flow rate is the frontal area times the velocity. The cage volume was fixed at 0.4 cu ft to agree with normal housing requirements for rats. Fan power is proportional to the product of the volume flow rate, Q, and the pressure rise, ΔP. In space vehicles, it is necessary to minimize power requirements. To reduce fan-power requirements, it is necessary to minimize the volume flow rate as well as pressure drop. The pressure drop is more a function of EC/LS ducting and equipment sizes rather than pressure drop inside the cages. Figure 5-3 shows the ventilation flow requirements as a function of the cage dimensions when the velocity and cage volume are fixed. From this plot, cage dimensions with 5- x 7-in. frontal dimensions with a length of 20 in. was selected. This configuration provides reasonable dimensions for the cage as well as a low flow rate of 12 cfm/cage. To further minimize the total flow requirements, 7 cages were installed in series allowing the 12-cfm particulate-matter sweeping flow to take care of 7 cages. A check on the increase in humidity and CO_2 concentration from the first to the seventh cage showed that the changes in these quantities were negligible. To complete the 70-cage complex configuration, 10 of the 7-cage series were placed in parallel to fit an available 120-cfm fan. Figure 5-4 shows the performance characteristics of this fan. Basically, the proposed animal cage configuration shown in Figure 5-1 was established from waste management considerations resulting from the scheme to use aerodynamic drag to sweep the air clear of particulate matter.

Ventilation and Thermal Control

The ventilation flow rates and velocities were established by waste management factors from the air-sweeping technique. A dry atmosphere is desirable in order to minimize decomposition of waste matter. Another factor related to humidity, from a comfort standpoint, is the temperature of the air. Information on the thermal comfort of animals is probably nonexistent, but it will be assumed to be similar to human beings. A dry atmosphere tends to allow higher ambient temperatures with comfort. Effective temperature is used as an empirical sensory index combining into a single value the thermal effect of temperature, humidity, and movement of air upon the human body. Comfort charts show that a dry atmosphere requires a higher temperature for comfort.

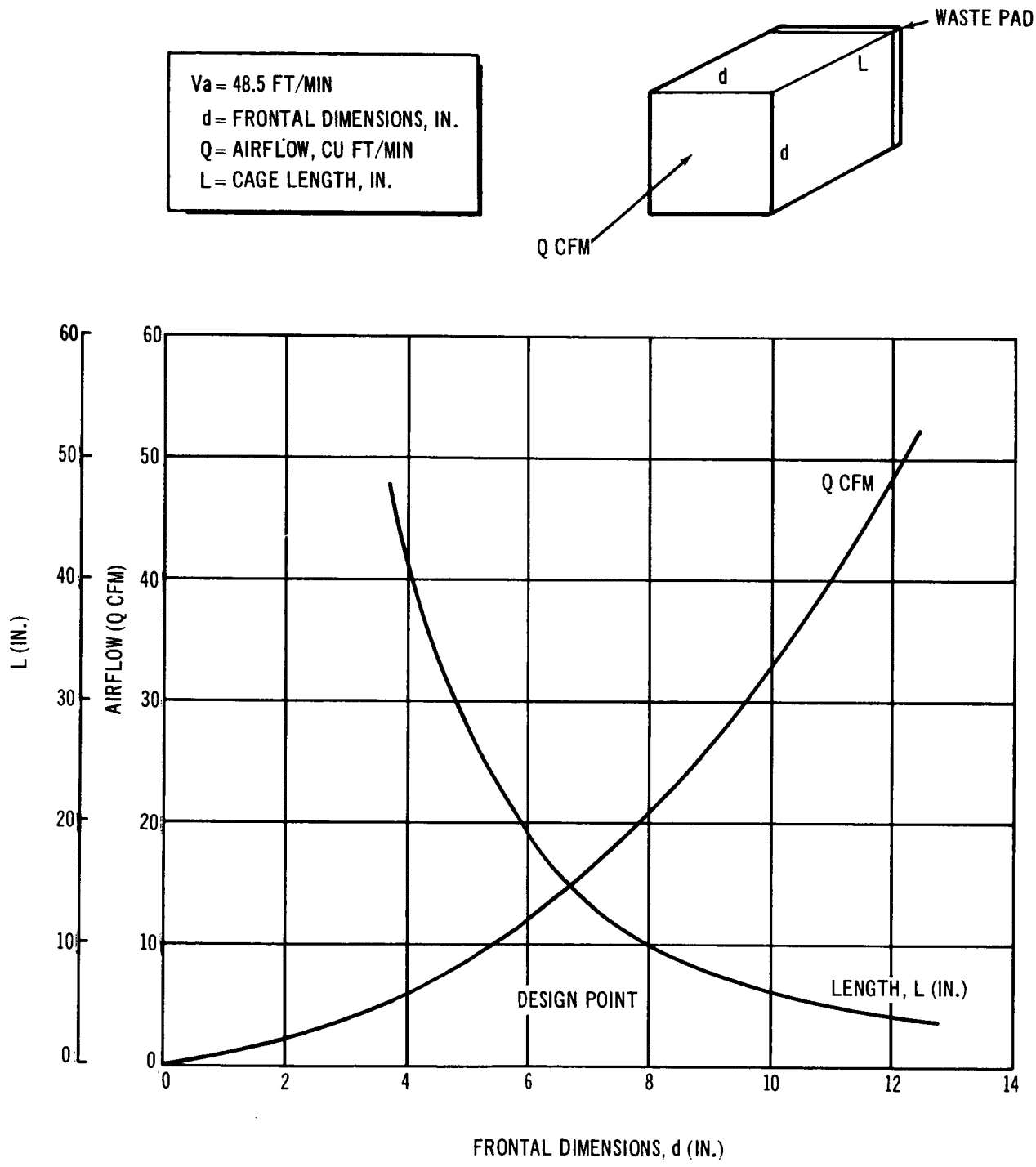


Figure 5-3. Airflow as a Function of Dimensions to Produce Sweeping Velocity

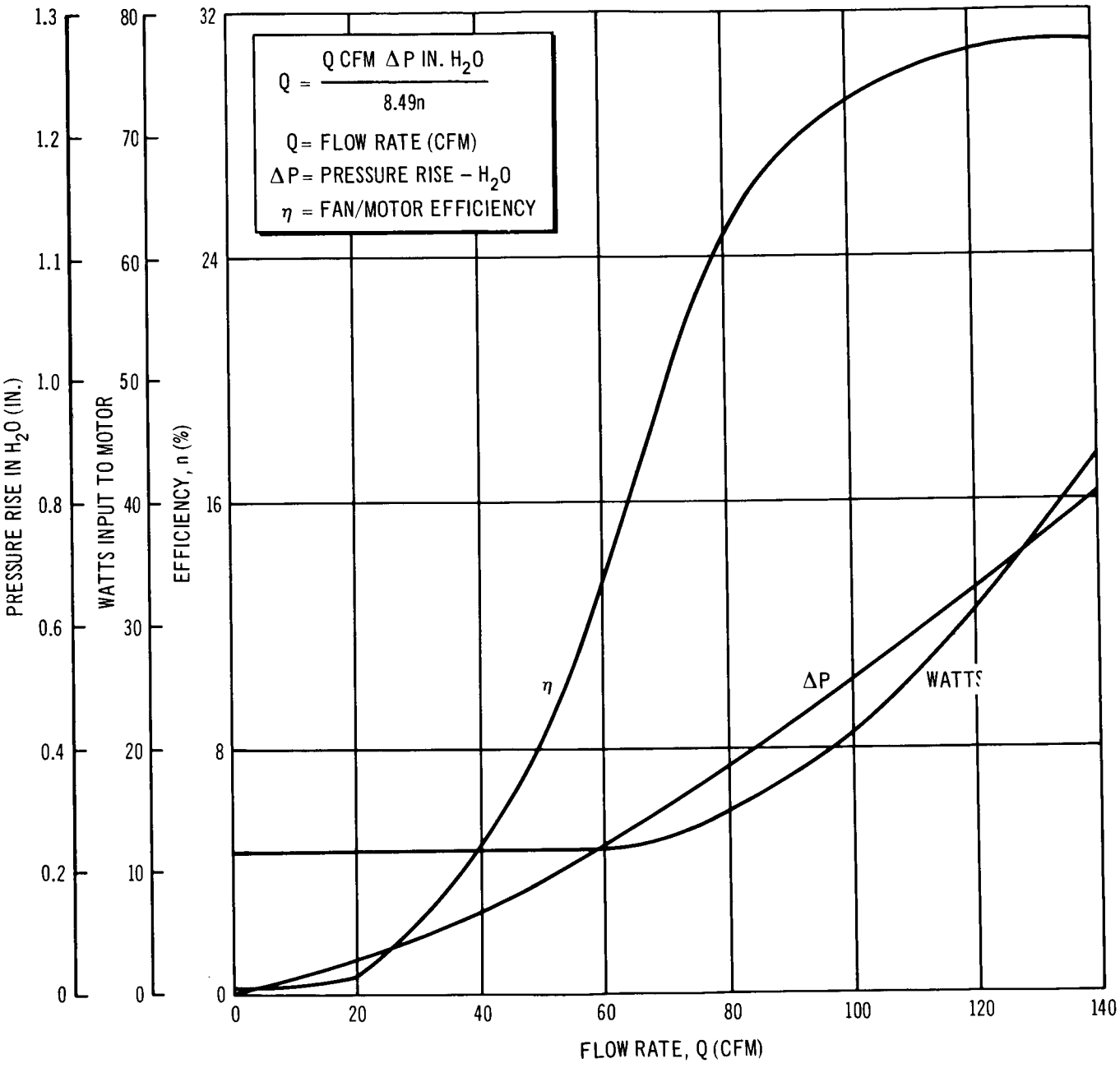


Figure 5-4. Ventilation Fan Characteristics

For example, at sea level with a relative humidity of 30%, an air velocity of 50 fpm, and a dry bulb temperature of 80°F, an effective temperature of 71°F is specified by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). This means that the subject feels as if it were 71°F instead of 80°F with the 30% relative humidity. In the animal subject EC/LS system, it will be possible to maintain higher temperatures in the cages when a dry atmosphere is maintained. Because of this, it is estimated that a temperature approximately 10°F higher than normal can be tolerated by the animals if a dry 30% relative humidity is provided.

A thermal-control system, which appears feasible and quite simple, involves heat rejection by radiation. It should be noted that the spent-stage workshop configuration involves passive thermal control without a radiator or coolant loop, and that heat generated internally is conducted through the walls of the vehicle. The front and sides of the cages are transparent plastic, which would transmit radiant heat energy. The inside and outside of the back surface would be made of material with a high emissivity. The back surface would radiate heat to the adjacent wall of the laboratory, and the inside surface of the back of the cage would radiate heat out through the transparent front and sides of the cages. The back surface of the cages would then have twice the surface area for heat loss through radiation. The radiant-heat-transfer characteristics with this configuration are shown in Figure 5-5. Because of the rather large surface area required for the cages, it is estimated that this form of heat rejection is all that is required from the EC/LS system. The Douglas Spent-Stage Experimental Support Module (SSESM) proposal had indicated that the walls of the laboratory would remain below 70°F at all times. A 5° to 10°F differential between the cage radiant back surface and the laboratory walls should radiate most, if not all, of the EC/LS system heat to the laboratory walls. In addition, some heat will be dissipated by convection from the cages and EC/LS equipment, and additional cooling will probably not be required. Some form of temperature control may be required, however, if the laboratory walls vary widely in temperature. This temperature control could take the form of a plastic venetian blind which can be opened or closed to vary the amount of radiator surface exposed. Rates for metabolic and EC/LS heat generated are shown in Table 5-1.

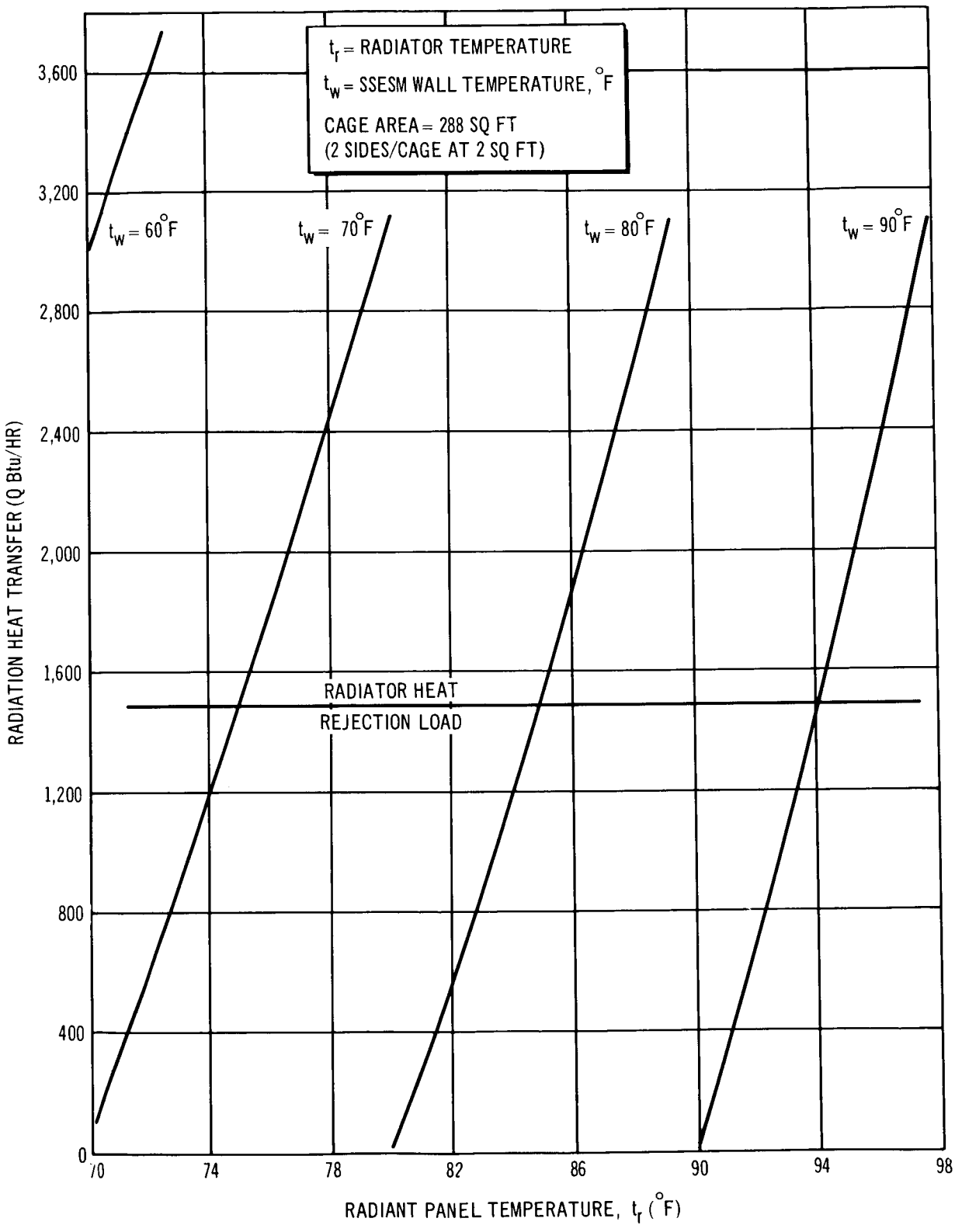


Figure 5-5. Radiant Heat Transfer as a Function of Radiator Temperature

Table 5-1

HEAT OUTPUT SUMMARY--METABOLIC AND EQUIPMENT HEAT GENERATION RATE (BTU/HR)

Metabolic Heat Output 144 Rats	EC/LS Fans Stationary Cages	Catalytic Burner Heater Plus Fans	Centrifuge Motor Plus EC/LS Equipment	Heat of Reaction $LICL+H_2O$	Heat of Reaction $LIOH+H_2O$
715	250	177	726	215	126

Evaporation of urine	Instrumentation power
-56	51

Totals 1,478 Btu/hour without centrifuge

2,204 Btu/hour with centrifuge

Notes:

1. Radiator Requirement, approximately 1,478 Btu/hour.

2. Centrifuge plus EC/LS equipment load to be rejected by convection from centrifuge and EC/LS equipment.

Carbon Dioxide Control

The CO_2 generated by the animal subjects will be removed from the atmosphere by passing a small quantity of ventilating airflow through a conventional lithium hydroxide canister. This material has an affinity for CO_2 and will absorb 0.92 lb CO_2/lb LiOH. Each of the cage EC/LS systems will have its own canister which is sized to provide the necessary CO_2 removal capacity for the mission duration of 30 to 45 days. Longer missions would require a resupply of this material. The flow rate through the LiOH canister will be established to maintain the CO_2 partial pressure in the animal cages below 5 mm Hg. Approximately 5 cfm is required for CO_2 removal. Activated charcoal is also included in the CO_2 removal canister for odor absorption.

Humidity Control

The moisture generated by the animal subjects is removed from the atmosphere by the LiCl desiccant in the humidity-control canister after the manner described in Reference 6. The canister is placed in a bypass arrangement around the main ventilation flow fan. This ventilation fan provides the necessary pressure rise to circulate a small volume flow through the LiCl canister. The quantity of flow passing through the canister could be varied with a small throttle valve, if necessary. The flow can be adjusted to maintain a minimum humidity of 30% relative humidity. This value has been specified for general confort of the animals. LiCl is proposed as the moisture absorbent because it has a high water capacity of 1.275 lb H_2O/lb LiCl. The material is deliquescent and it will present some canister design problems. However, the problems are considered to be solvable by development and design. The heat of reaction of LiCl and H_2O is 1,413 Btu/lb H_2O. With the small quantity of water being absorbed, the canister will be able to reject this heat to the laboratory atmosphere without difficulty.

Alternate Approach

An alternate method for a nonregenerative system would be the use of a metallic superoxide, such as KO_2 or NaO_2. This would absorb all of the CO_2 generated by the animals, absorb 21% of the water output, and supply all of

the oxygen required. The theoretical reaction is as follows: $2\ Na\ O_2 + 1.5\ H_2O + CO_2 \longrightarrow Na_2\ CO_3 \cdot 1.5\ H_2O + 1.5\ O_2$. The remainder of the water is then absorbed by a solid absorbent placed downstream of the $Na\ O_2$ in the same canister. Such a system would result in considerable weight savings with regard to oxygen and lithium hydroxide consumables and warrants consideration in future studies.

Trace-Contaminant Control

A catalytic burner is included in the EC/LS system for the removal of such possible trace contaminants as carbon monoxide and methane. The burner operates at temperatures of 600° to 750°F, and it will effectively destroy any bacteria which may be in the ventilating air. An oxidation catalyst oxidizes carbon monoxide and methane at 100% efficiency with a 750°F temperature. A regenerative heat exchanger is employed which heats the incoming air while cooling the outlet air from the catalytic burner. An electrical heater is used to provide startup capacity and to make up for heat losses during operation. Approximately 16 W of electrical power is required by the proposed unit for the heater. A small fan is required to produce the necessary pressure rise through the regenerative heat exchanger and catalytic burner. The normal ventilation fan in parallel with the burner unit will not provide an adequate pressure rise for proper operation of the catalytic burner. The power requirements for this unit are quite nominal because of the low flow, and an estimated 10 W fan should be adequate.

Centrifuge EC/LS System

The EC/LS system provided for the animal subjects riding the centrifuge is basically the same as the ones for the stationary cage complex. Because of the centrifugal acceleration provided by the centrifuge, aerodynamic drag is not necessary to move the particulate matter to the waste pads, and they are located on the outer radius of the cages. The induced gravity or g-force provides a greater acceleration outward in a radial direction for waste control than the aerodynamic drag does in a tangential direction. The air blown through the cages is for thermal and ventilation reasons. Air does provide the necessary drying effect to evaporate the urine and to dry the feces on the waste pads. Heat rejection is mainly by convection rather than radiation

since the motion of the cages provides adequate convective heat transfer. The atmosphere from stationary EC/LS equipment is ducted through the rotating hub to and from the cages by means of hollow spokes and returned to the EC/LS equipment. This arrangement permits having a closed-loop system for the centrifuge system which is similar to that for the stationary cages.

5.1.1.2 Electrical Power Requirements

Requirements which originate with the manned operation of a workshop (lighting, crew EC/LS, communications, control, etc.) are considered fundamental to the mission and are not discussed. Only the loads imposed on existing electrical power resources are described.

Demands for electrical power originate almost entirely from the animal EC/LS system. Table 5-2 shows the power requirements for the two types of workshop mission programs. (See Section 2.) The first one, a short-term mission (less than 45 day) involves a limited number of animals without a centrifuge. The long-term mission will involve more animals and will include a centrifuge for reconditioning or other research.

The loads listed in Table 5-2 are continuous loads and would be required throughout the mission, once the facility were setup. In addition, the capsule in which the animals are transported and stored before facility setup will require 64 W.

Table 5-2
ANIMAL RESEARCH FACILITY POWER LOADS

	Short-Term Mission	Long-Term Mission
Ventilation fans	87	130.5
Catalytic burner	52	78
Controls and instruments	10	15
Centrifuge motor	---	150
Total	149 W	373.5 W

5. 1. 1. 3 Data Requirements

The data requirements of an animal research facility have been separated into two categories: those associated with the operation of the equipment and those associated with the animal experiments.

The equipment measurements are shown in Table 5-3. These measurements would be fed into the workshop data system. Channel frequency response requirements would be less than 6 Hz. Sampling rates for these measurements are very low, 1 sample/sec being more than adequate. Ideally, with on-board data-compression techniques the measurements would only be stored for later transmission if the parameter moved outside predetermined limits. Provision must be made for a real-time display of these parameters to the crew. A failure alarm, signalling an out-of-tolerance condition, is also required.

The basic biological measurements required from each animal are heart rate, body temperature, and respiration rate. In Section 7 of this report, a means is suggested which will acquire this data external to the animal. This method will appeal to biologists who dislike perturbing animals with implanted telemeters. However, the use of implanted telemeters is a well established approach and would provide more reliable data not subject to the behavior of the animal.

Two methods of acquiring the data from many animals with implanted telemeters is shown in Figure 5-6. In the first circuit, a pick-up probe in each cage feeds into a common antenna buss. Each animal in the complex is assigned a channel between 80 and 108 mHz. The composite signal from the antenna is amplified and fed to a converter, where it is mixed with the signal from a local oscillator. The local oscillator frequency is selected by the format logic circuit, thereby selecting the proper telemeter signal for the position in the data format. The converted signal is then fed to a discriminator which extracts the data.

In the second circuit, a pick-up probe and converter is located in each cage. The 80- to 108-mHz signals from the telemeter are converted to 10. 7 mHz, amplified, and fed through individual coaxial cables to a multiplexer, where they are sequentially fed through a discriminator and encoder to the data-storage system.

Table 5-3
EQUIPMENT MEASUREMENTS

Items	Without Centrifuge	With Centrifuge
Temperatures		
Ventilation fan inlets	2	3
LiCl and LiOH canister outlets	2	3
Catalytic burner	2	3
Laboratory ambient air	1	1
Pressures		
Housing partial CO_2	2	3
O_2 supply	1	1
Laboratory	1	1
Humidity		
Animal housing relative humidity	2	3
Flow		
Housing atmosphere	2	3
Rate		
Centrifuge rpm		2

The first approach is recommended because it involves less total equipment and cabling.

Visual observations will make up a large percentage of animal experiment data. This includes not only the scale readings on laboratory measuring equipment, but also comments by the experimenter on the progress of an experiment and the condition of the animal subject. Scale readings will be written down by the experimenter and either returned to Earth in a data-return package or recorded on a voice recorder and later transmitted. Because of the time involved and the likelihood of errors in transcribing, the latter method is not recommended. Experimenter comments, however, will be recorded, preferably at the time of the observation.

Photographic and television coverage of experiments will be essential. Color stills will provide means for eventual Earth evaluation of the experiment. In animal behavior experiments, or when laboratory techniques are being tested, motion picture coverage will be required for later studies on Earth. The use of motion picture film creates problems of supply, storage, and return. Television signals, on the other hand, may be stored on tape and returned to Earth during the next data dump period.

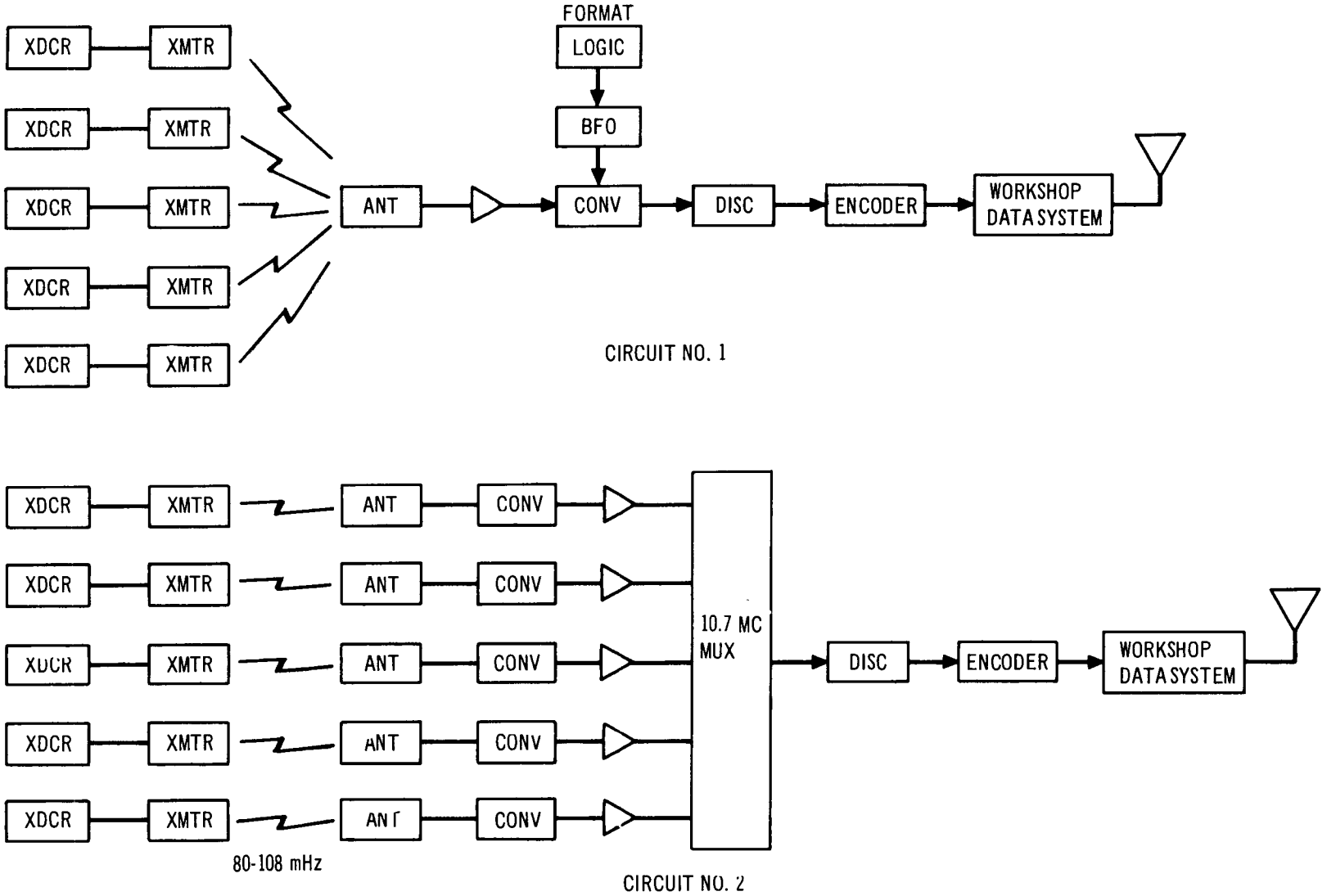


Figure 5-6. Implant Telemeter Data System

5.1.1.4 Animal Subject Centrifuge

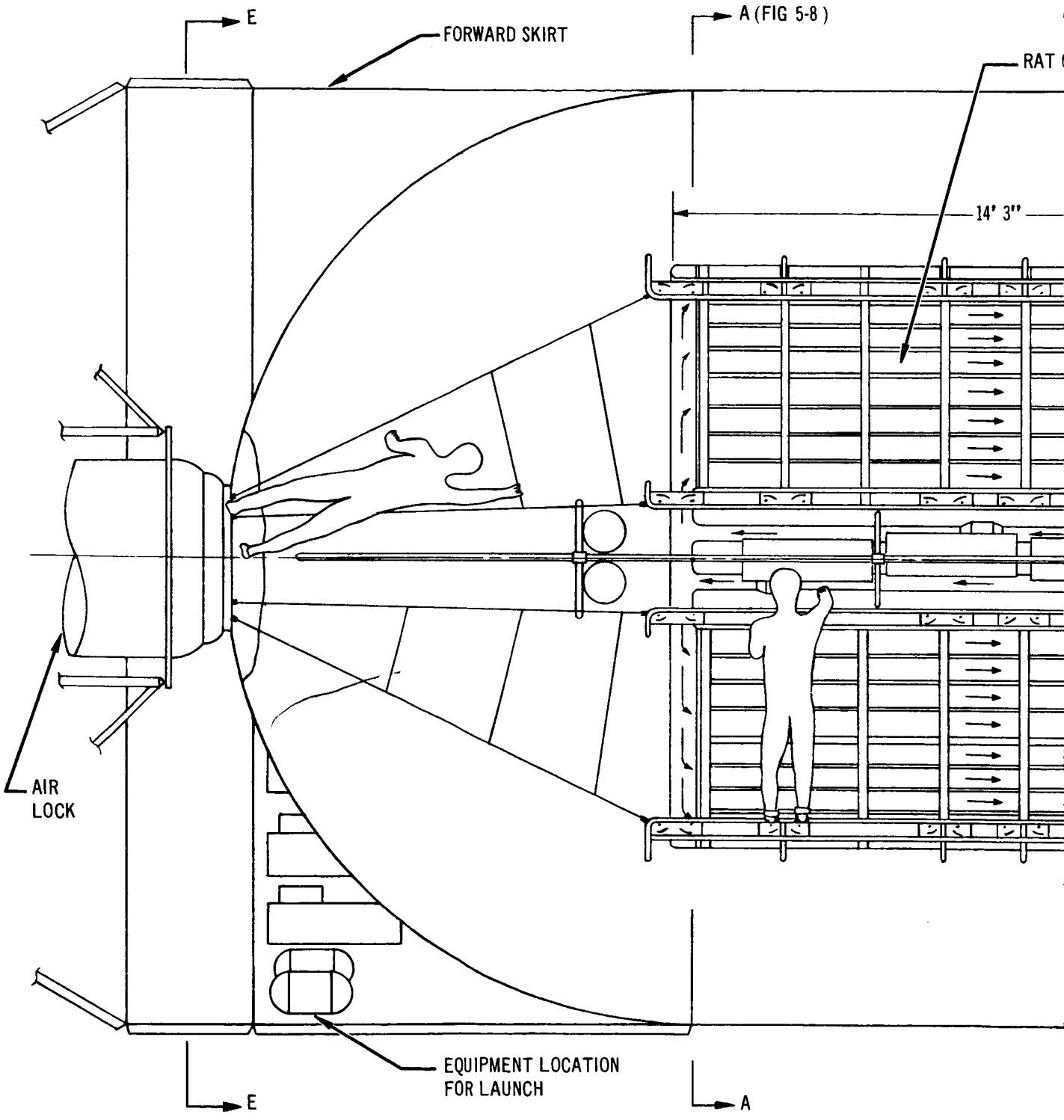
Two centrifuges could be located in a workshop configuration at the common bulkhead end of the LH_2 tank (Figures 5-7 and 5-8). They would operate at speeds of 7 and 18 rpm to produce gravitational forces equivalent to 1/6 g and 1 g, respectively. The concept presented is of tubular construction and of a material or materials having similar coefficients of thermal expansion. The basic centrifuge structure would be installed in the tank prior to launch and hence would be subjected to approximately 500°F temperature variations. The centrifuges, which rotate about a common hub, will be supported by a rod or cable system and will be unsupported at the common dome during launch. After launch and when the centrifuge and its supports have warmed up, one end of the hub would be fastened by bolting or another method to the common dome (Figure 5-9). A rod-tensioning system would be adjusted to support the other end of the hub (Figure 5-8).

The two centrifuges would be counterrotating, coupled by a planetary gear system and driven by one motor installed after launch. The cages mounted on the centrifuges would be supplied with air through a rotating manifold in the centrifuge hub as shown in Figure 5-9. A water reservoir and distribution system would be located on each centrifuge, as well as food storage, distribution, and feeding devices.

A centrifuge control station would be located at the tank wall (Figure 5-8) adjacent to the wall-mounted cage installation. At this location, the centrifuge start-stop controls and required technician restraint devices would be located to facilitate care, feeding, and performance of various experiment tasks associate with the centrifuge-mounted animals.

5.1.1.5 Animal Cage Facility

In a spent-stage or workshop facility, the animal-cage facility must be set up and activated after stage passivation. To minimize the number of tasks required, the concept of a partially preinstalled cage facility evolved. Figure 5-7 shows a complete cage facility for 144 rats. It is expected that a major part of the facility, including the cages, ducts, and centrifuges, could be ground fitted. Only such equipment as motors, filters, instrumentation, cage



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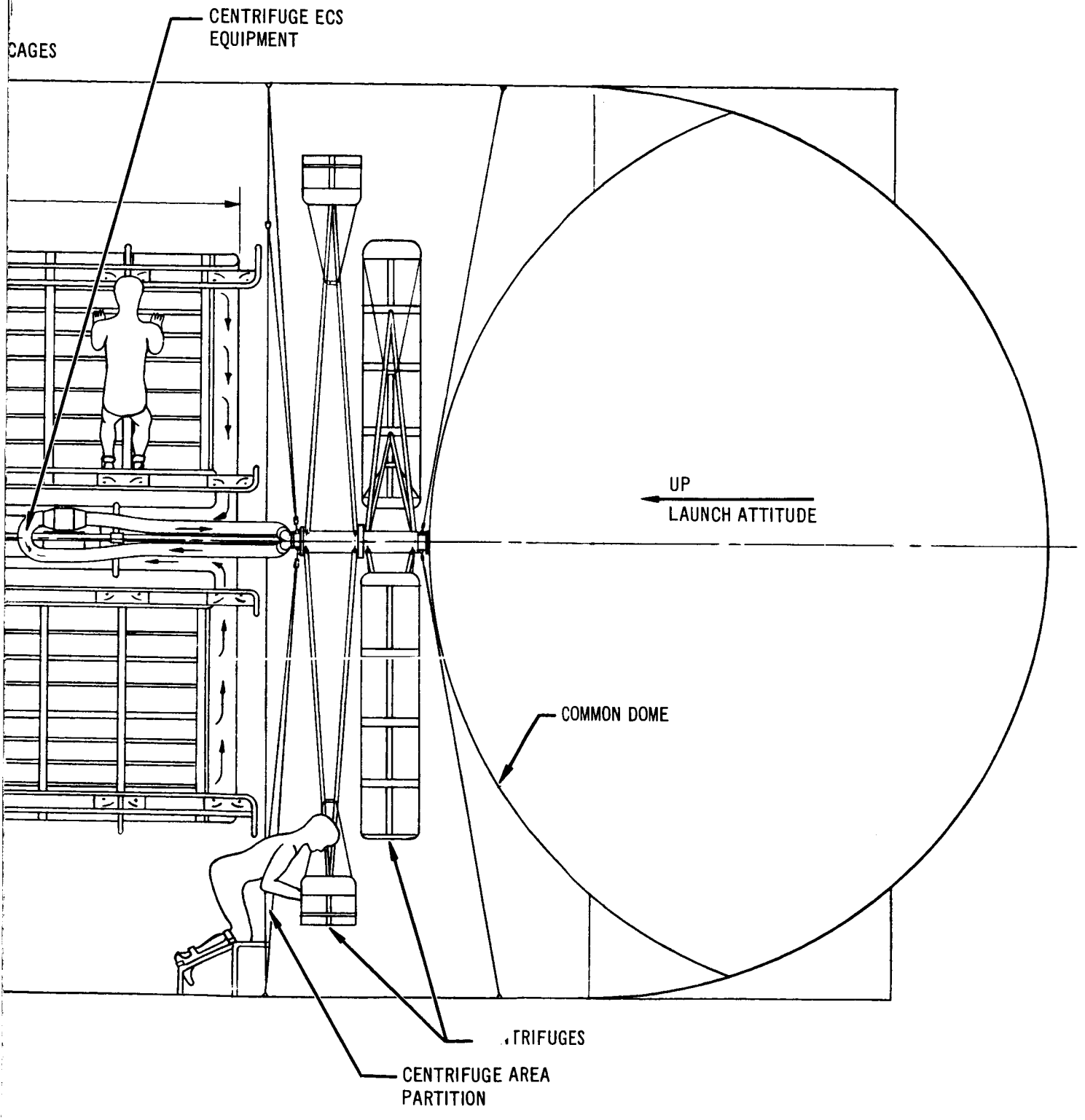

Figure 5-7. Cage Facility Elevation S-IVB Workshop

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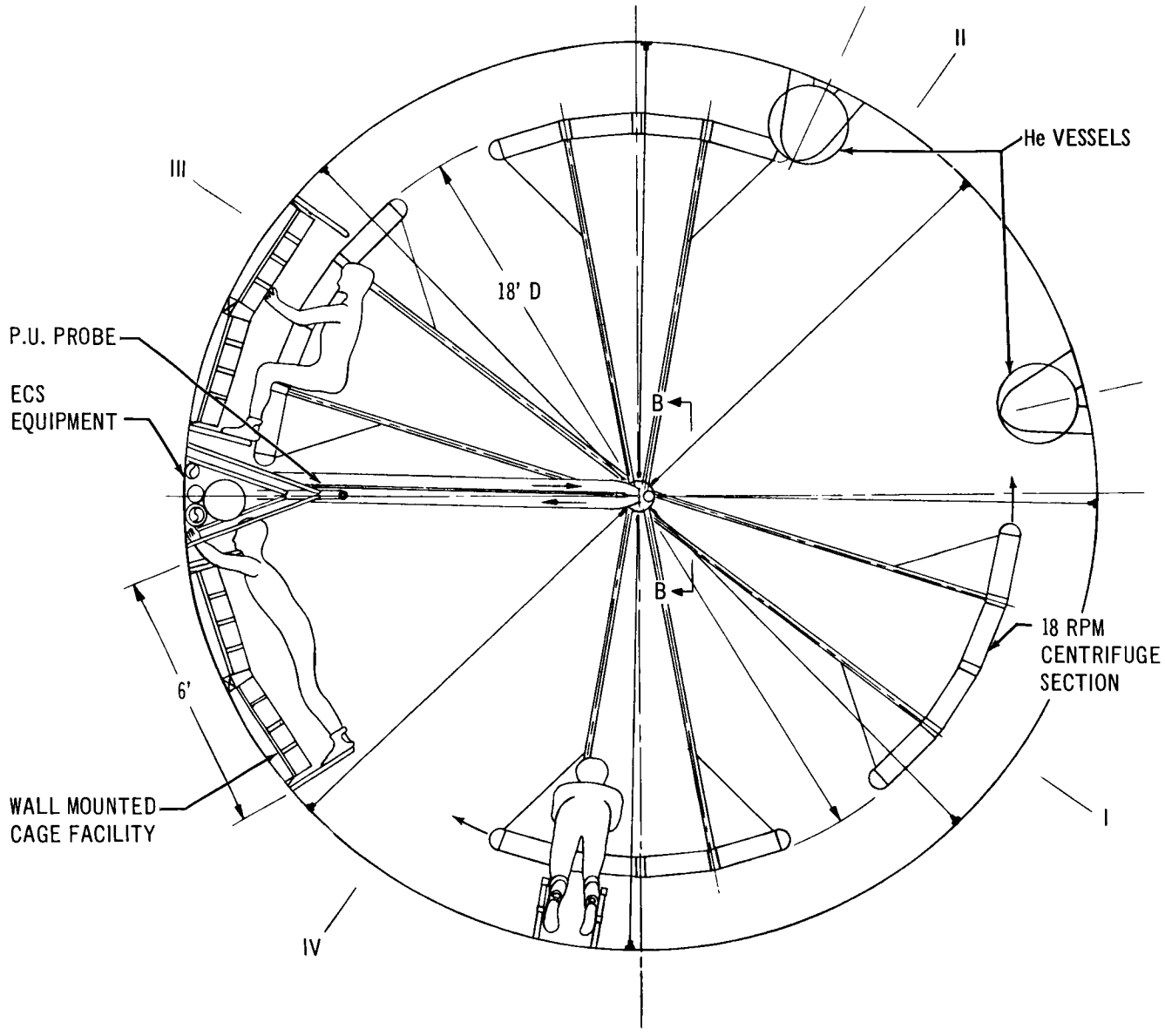
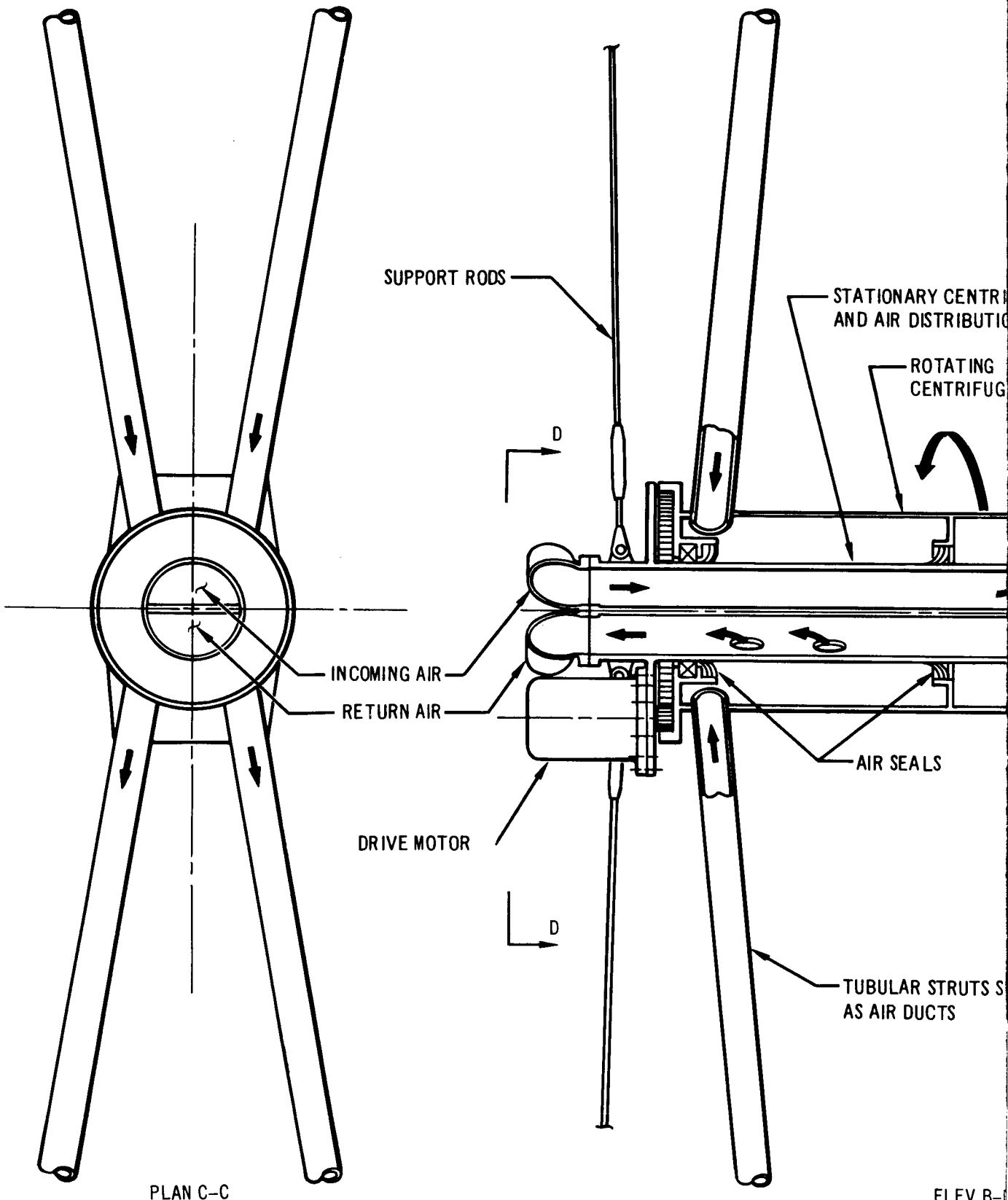


PLAN A-A (FIGURE 5-7)

Figure 5-8. Laboratory Area Omitted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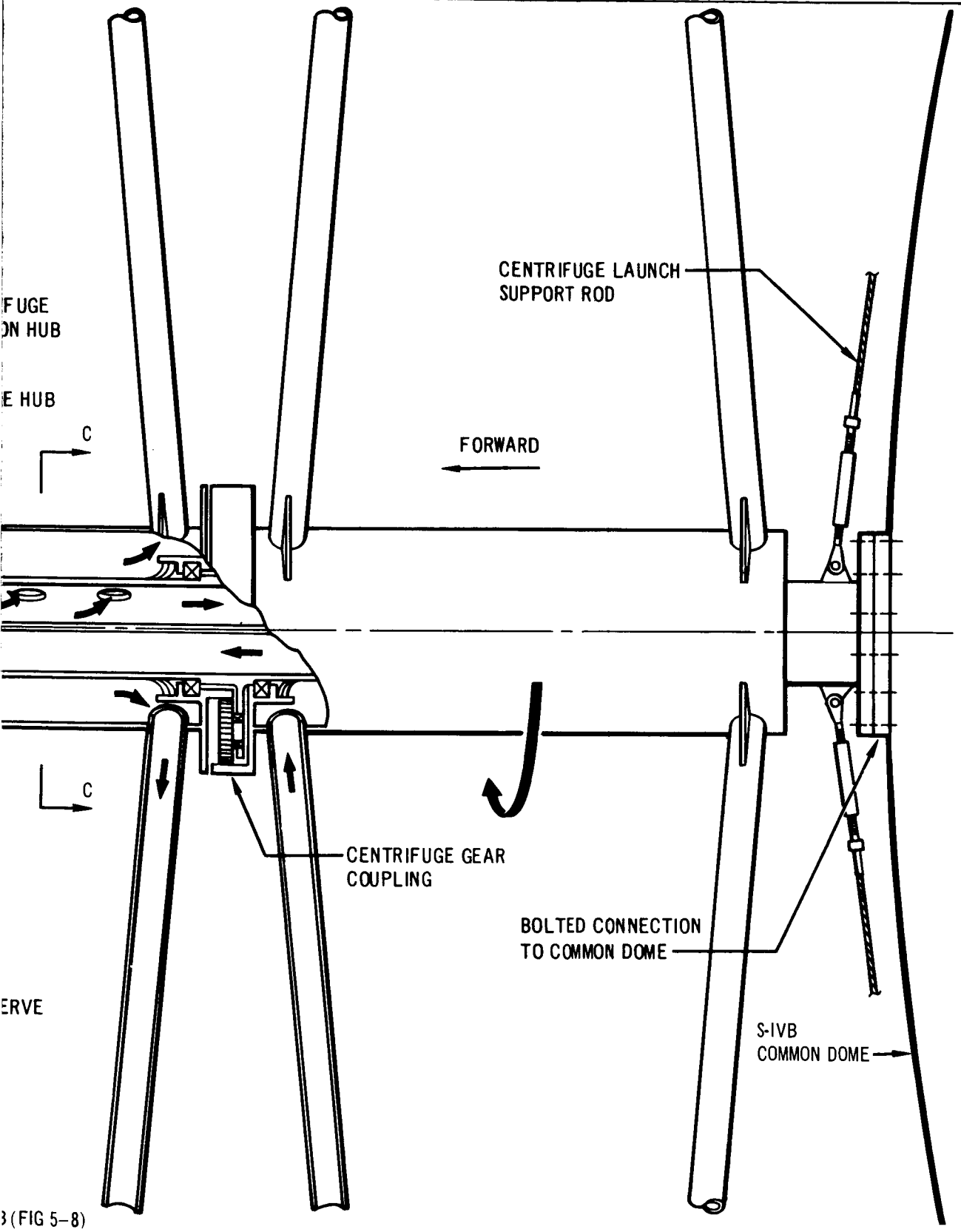

Figure 5-9. Centrifuge Hub

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covers, and the animals themselves would be carried in and installed after stage passivation. These latter items would be stored prior to installation around the S-IVB forward skirt (Figure 5-10).

In Figure 5-8, cages are located in three areas. Two groups of 56 cages are located at the wall of the liquid hydrogen tank on both sides of the propellant utilization probe. Thirty-two other cages are mounted in groups of eight at each end of two centrifuges. Equipment for three separate closed-loop ECS is located between the propellant utilization probe and the tank wall. In this same area would be located food, water, and other experiment-support equipment. This layout illustrates cages for rats only. These cages are 5 in. x 7 in. x 18 in. long, with the 7-in. cage width facing the technician (Figure 5-11). The cages are airtight and operate at a slight negative pressure (1 in. H_2O), with air flowing through series of paths of seven cages each. Air to these cages passes through a rotating hub manifold system as shown in Figure 5-9.

Not shown, but required, will be watering and feeding systems for all stationary and centrifuge mounted cages. Food and water supplies for the centrifuge-mounted cages will be located on each centrifuge.

The rat cage (Figure 5-12) is typical of cage concepts applicable for smaller primates, including dogs and cats. This cage would be constructed of translucent material, such as fiber glass, with a stainless-steel wire liner. The fiber glass will withstand the imersion in LH_2. The stainless steel wire liner provides a gripping surface and also prevents the animals from gnawing through the sides of the cage. The wire liner could also be electrically insulated and could serve as an antenna for animal inplant transmitters.

The cage access openings have transparent covers for animal viewing or provide a mounting for such special experiment equipment as rat activity modules. The cage volume could be as large as 0.4 cu ft, have a 5- x 7-in. rounded rectangular cross-section, and be about 18 in. long for rats. Air from the ECS will move lengthwise, passing through a waste filter at the downstream end of each cage. Air will pass through a series of loops of seven cages each. Loose feces and urine will be carried by air motion to the

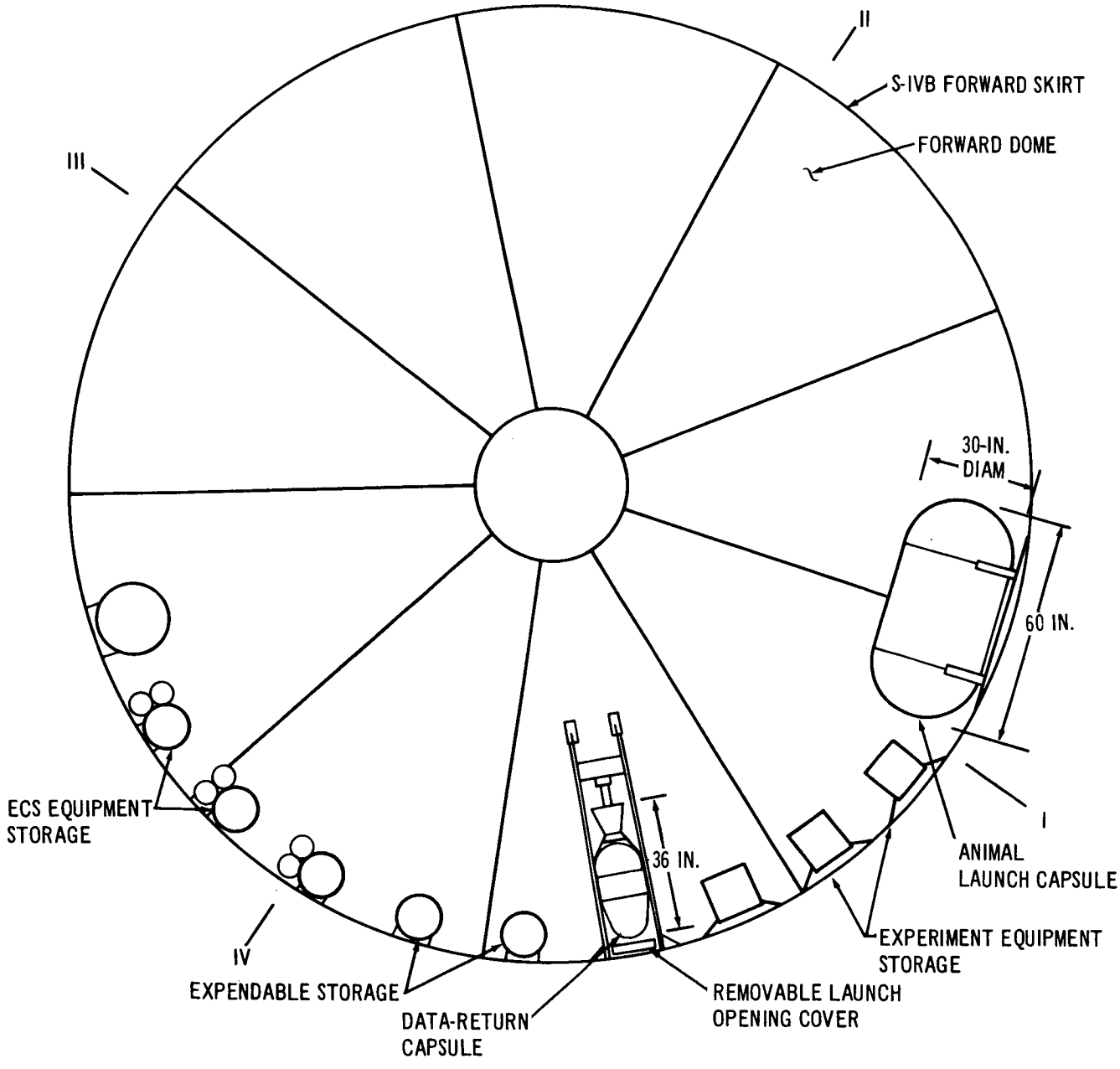

Figure 5-10. Stored Equipment Layout – S-IVB Forward Skirt

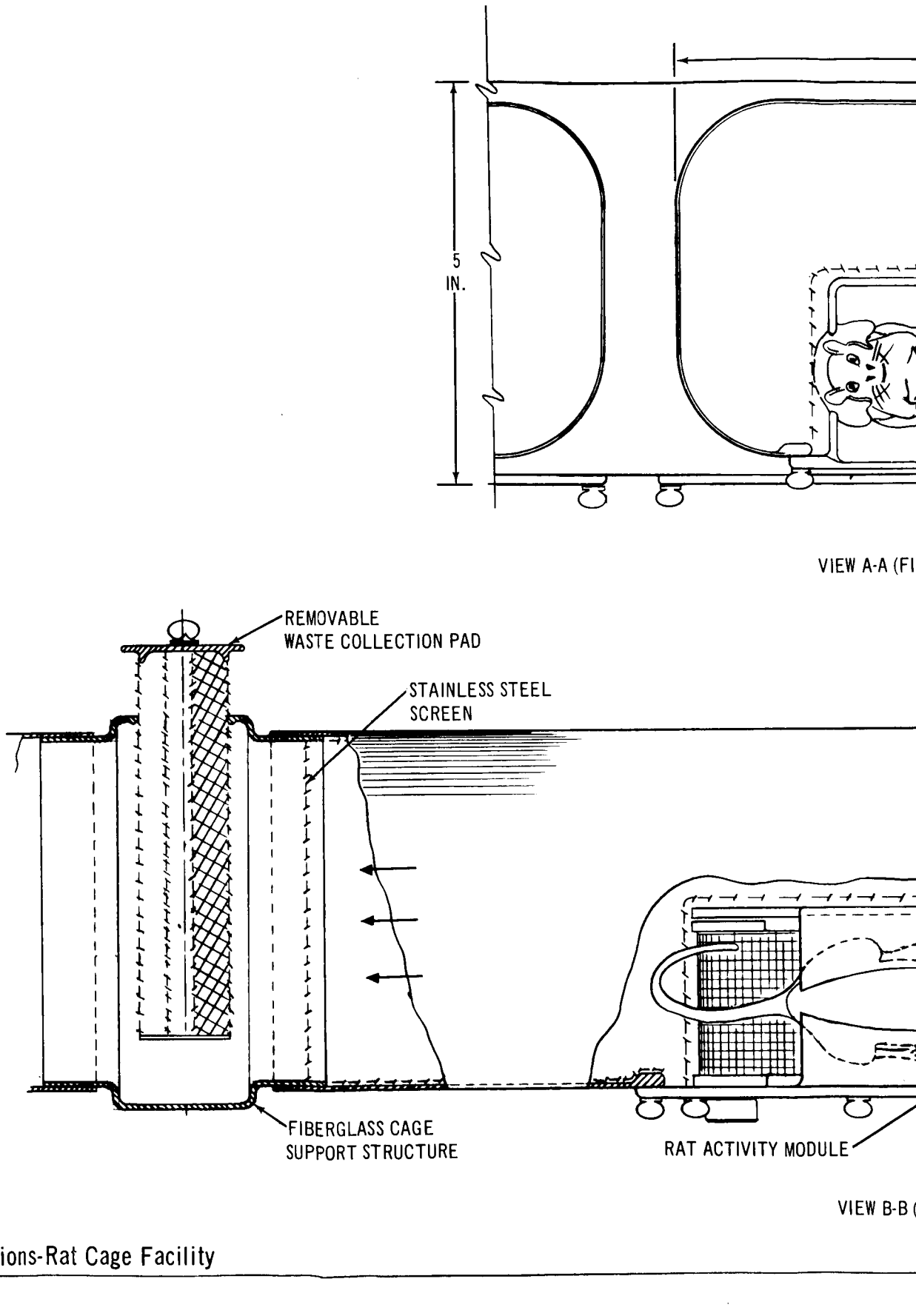

Figure 5-11. Sections-Rat Cage Facility

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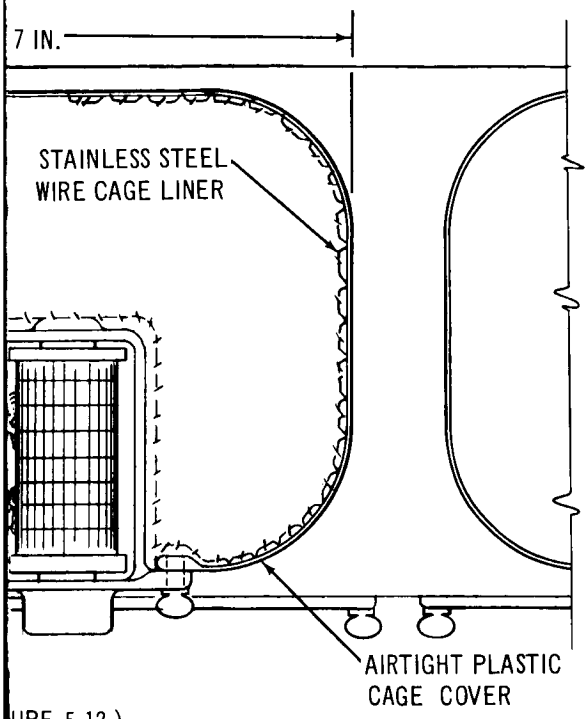

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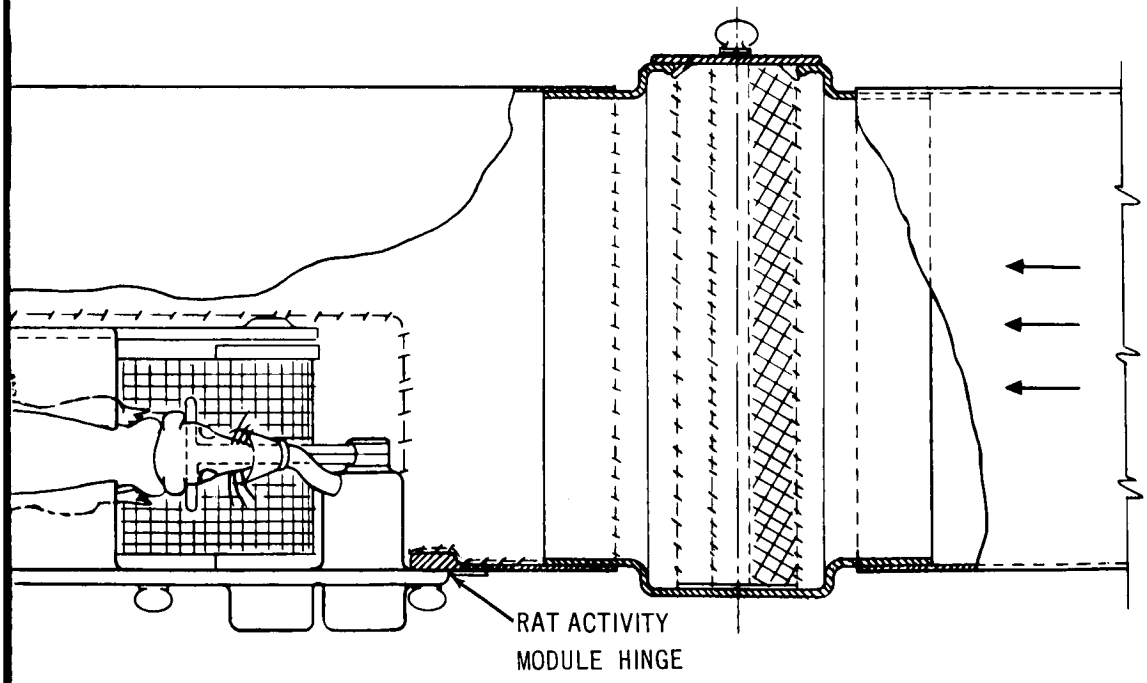

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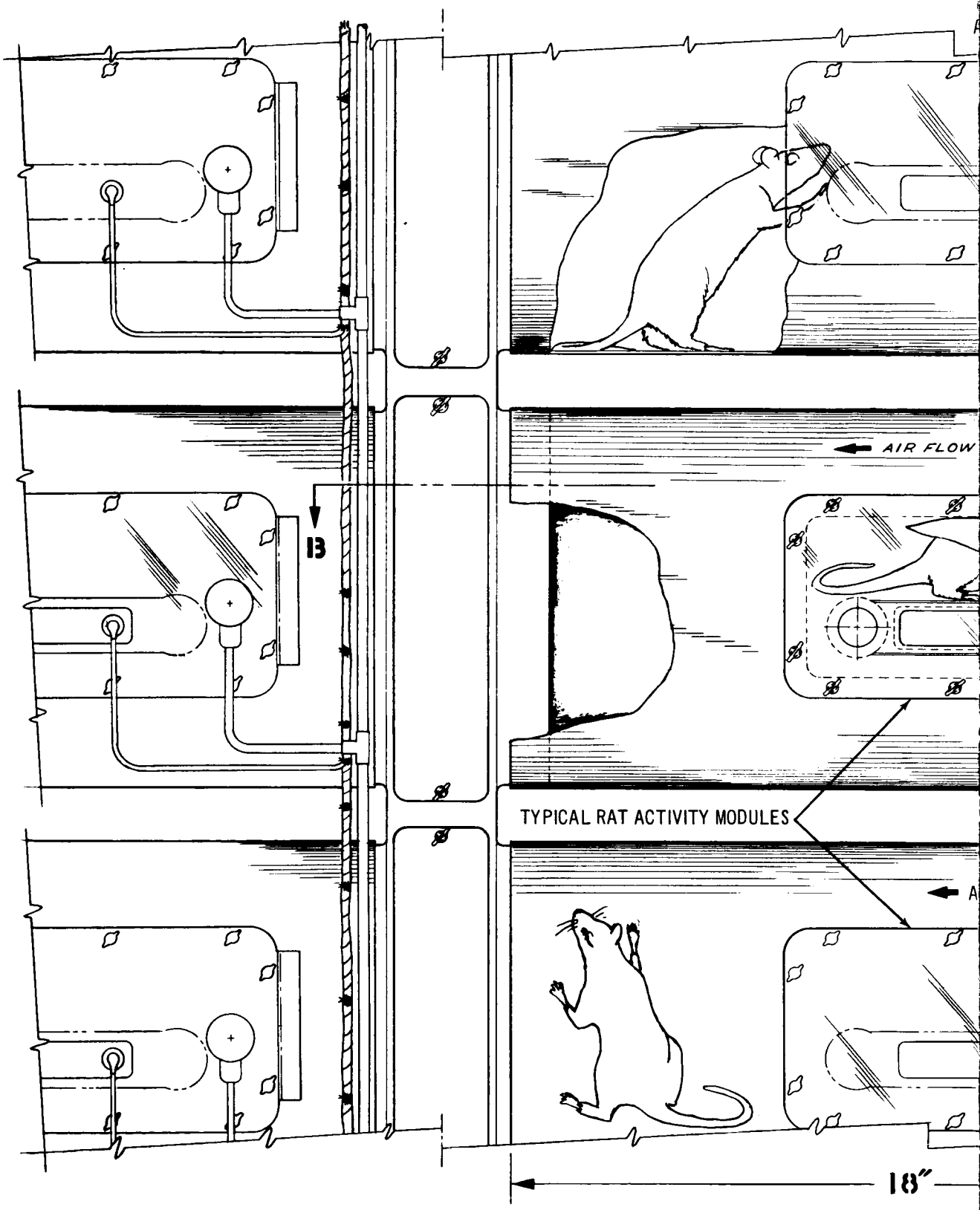

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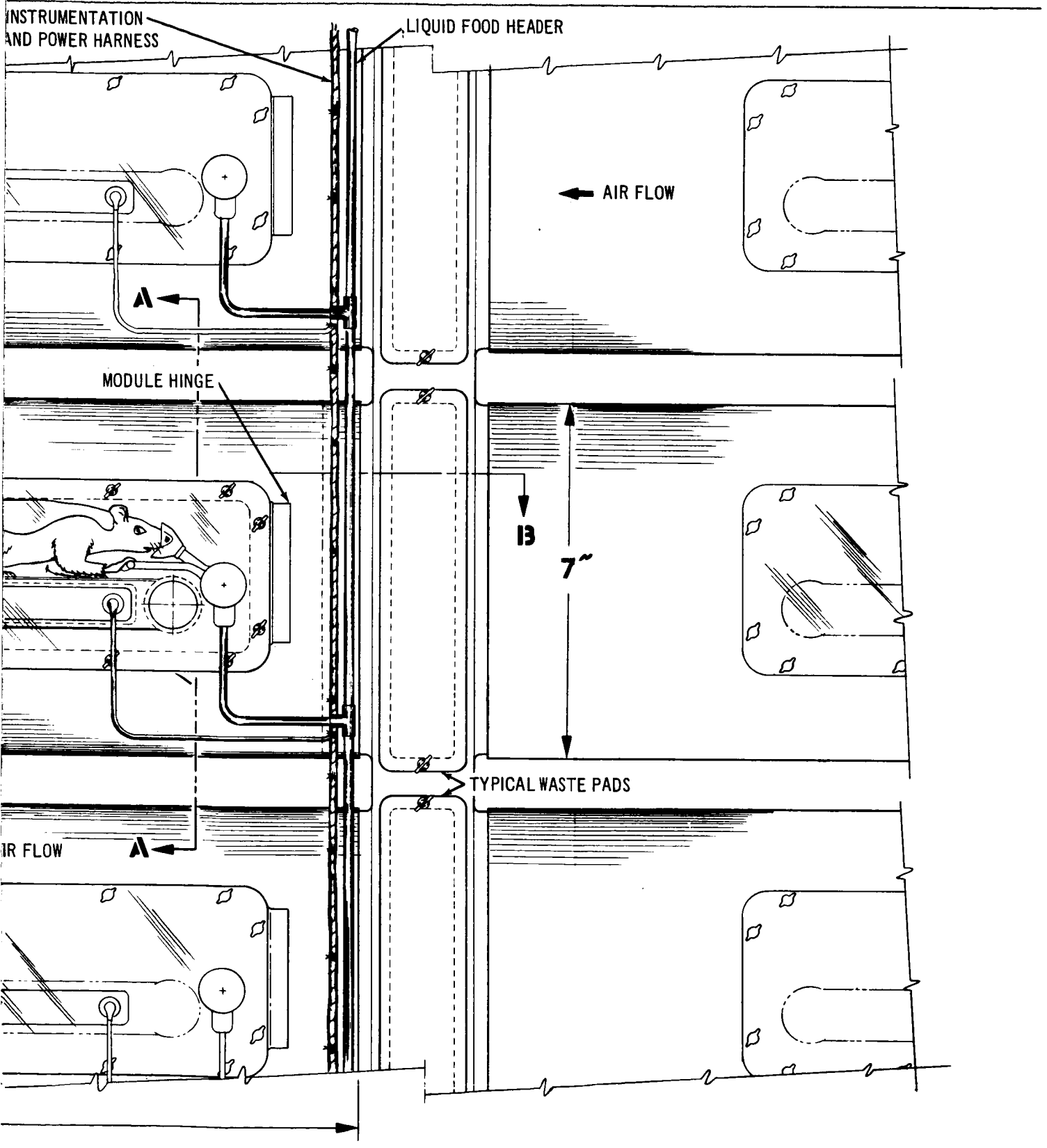

Figure 5-12. Elevation H-H (Figure 5-8) Rat Cage Facility

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filter end of each cage, where it will dry. Filters will be sized to function for up to 30 days without being replaced.

5.1.1.6 Animal Subject Transfer Module

An animal-subject transfer module is required to house animal subjects prior to facility activation on any workshop or spent-stage mission. The module must be capable of automatically providing all essential life-support requirements for prelaunch and post-launch periods, which may total several days. The module must maintain a suitable temperature; humidity; atmospheric pressure; and oxygen, nitrogen, and CO_2 partial pressures. In addition, it must have provisions for feeding, waste management, exercise, and the instrumentation required to measure and transmit critical animal biological functional parameters. Section 7.3.1.1 describes a concept of a prototype animal-launch capsule capable of supporting 16 rats.

5.1.1.7 Orbital Storage Requirements

Unattended operation of the animal-subject laboratory in orbit will involve some changes in the system design. Basically, the system is an automatic system which requires a minimum amount of attention by the crewmen. However, an attendant could replace or repair malfunctioning equipment and would have direct observation of the animals in their cages. An ailing animal could be segregated or possibly sacrificed, if necessary, while unattended operation would require some form of remote control and monitoring capability.

To make the EC/LS capable of unattended operation, some changes to the proposed EC/LS system would be required. A preliminary evaluation of necessary changes would include the following items:

1. Provision of such redundant components as fans and valves with automatic switchover to the standby unit if a failure in the primary unit occurs.
2. Provision of remote biomedical and related equipment-monitoring capability. A television system may be necessary.
3. Monitoring of such EC/LS parameters as P_{O_2}, P_{CO_2}, temperature, and humidity.
4. Provision for isolation of ailing or deceased animals.

5.1.1.8 Concepts of Crew Mobility Control and Restraint Device

Crew mobility control and restraint devices are essential for effective manned operation of any zero-g orbital laboratory facility. Restraint device requirements are, indeed, so fundamental that their consideration must be included in, and many times governs, equipment layouts. Restraint hardware becomes a dominant constraint for configurations such as the animal-cage facility (Figure 5-7) which requires technician access over a large area. Two types of restraint-system concepts were considered in most MOARF layouts, a lower-leg restraint system and a foot restraint system.

A leg restraint system is shown in Figure 5-13. This system utilizes "pole climber" type leggings, with lugs near each knee and foot which can be inserted in support sockets. The lug sockets would be oriented in square patterns, four being required to completely anchor the technician's legs at any one location. The sockets would incorporate spring-loaded-balls detents which engage the restraint lugs to prevent their inadvertent disengagement. The leg restraints can be positively locked in place by turning and releasing a spring-loaded pin at the knee lug socket. Normally, leg restraint engagement would be maintained by a light outward pressure at the knees, since the lug at the foot cannot be disengaged as long as the lug at the knee is engaged.

A second restraint concept utilizes shoes with lugs and slotted plates (Figure 5-13). The feet can be locked by inserting the two lugs into mating slots and rotating the foot through a small angle. A handhold must be used during engagement and disengagement. It is proposed that the anchor plates be attached to tubes and, as shelves, be located in rows on approximately 72-in. centers. One row could act as a handhold while the feet were being engaged to the other. Head and foot orientation could be reversible between rows.

5.1.2 Spent S-IVB Installations

The two experiment programs studied in spent-stage missions reflect different requirements. The two installation configurations which accommodate these programs are described in this section.

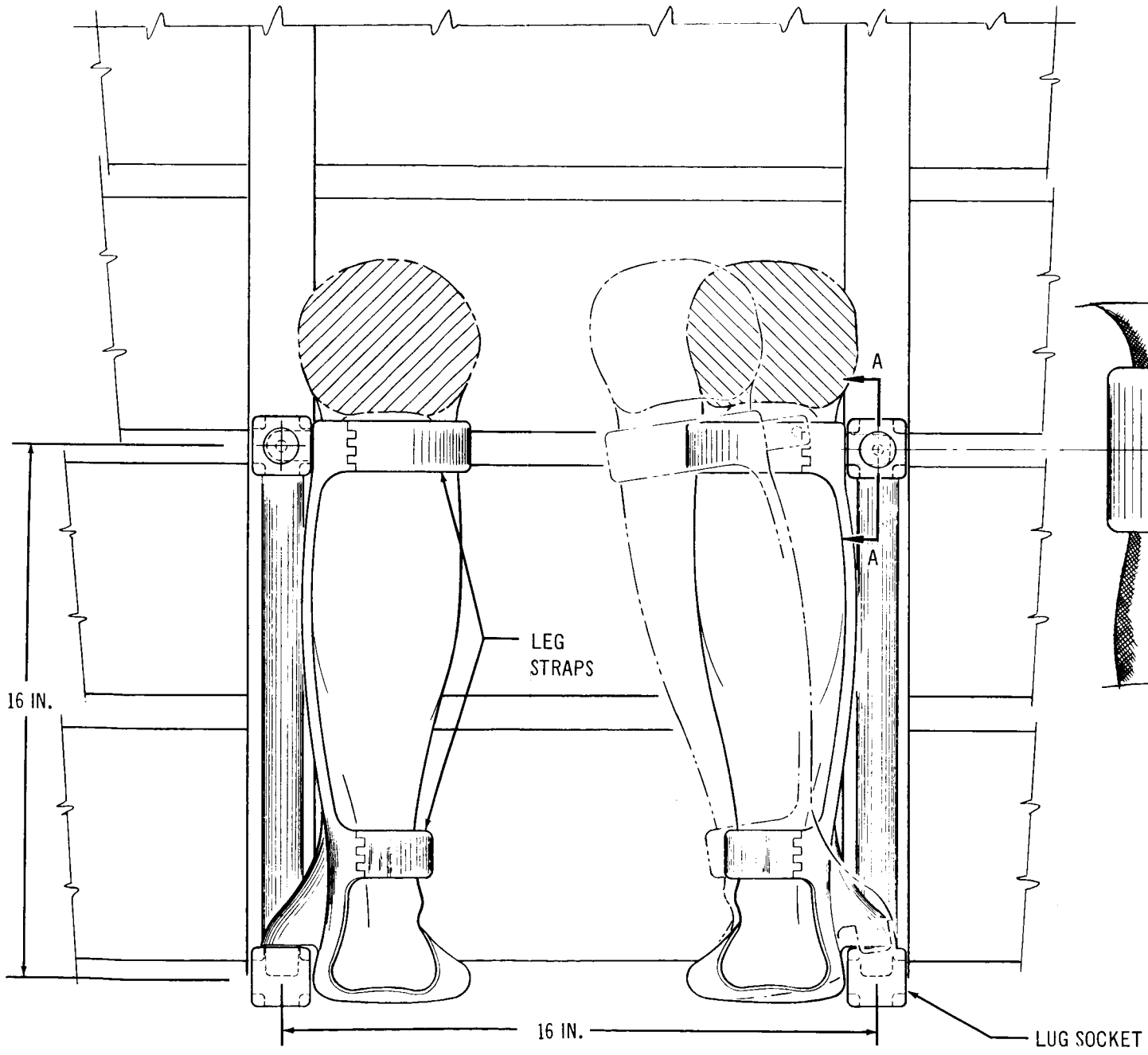

Figure 5-13. Leg Restraint Device Concept

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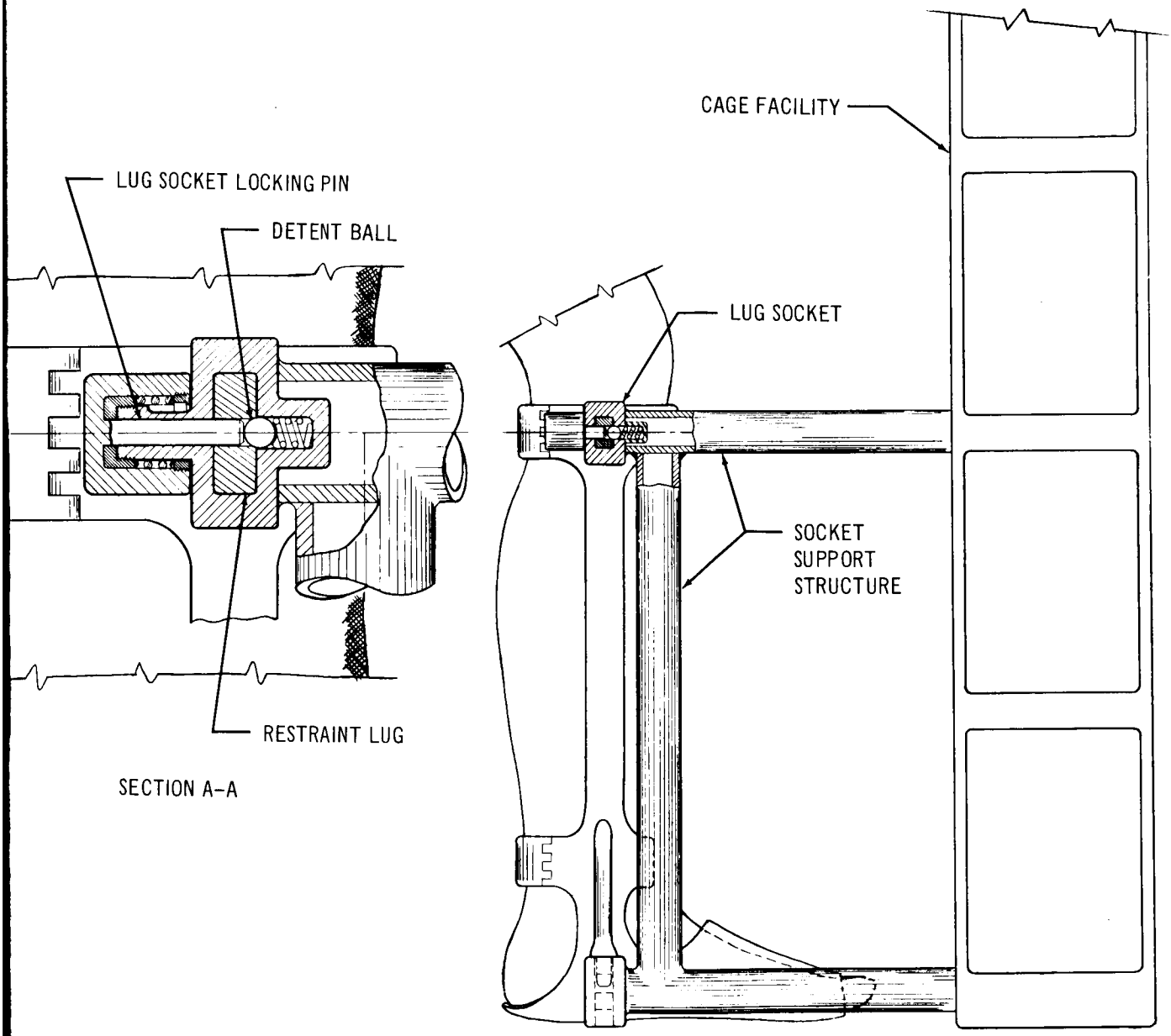

SECTION A-A

SIDE ELEVATION

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5.1.2.1 Short-Term Mission Installations

A short-term mission is defined as a single- or dual-launch workshop launched for an approximate 30-day duration. The duration would be determined by the support capabilities of the airlock. A short-life, limited-payload orbital facility precludes the usefulness of centrifuges, permits the use of only rudementary laboratory facilities and would produce limited biological data. A facility concept consistent with this type mission is shown in Figure 5-14. The basic animal facility arrangement is similar to a long-term workshop mission (Figure 5-7) but does not include a centrifuge. The workshop payload weight allocated to this program would be determined by the number and types of animals to be involved and the extent of the experiment program. Figure 5-14 shows a typical workshop arrangement and a rat-cage facility for 112 rats which is described in Section 5.1.2.2.

5.1.2.2 Long-Term Mission Installations

A long-term mission (90 to 360 day) animal research facility concept is depicted in Figures 5-7 and 5-14. The facility is shown laid out in an S-IVB workshop which is a spent S-IVB. This means the stage is launched "wet", with only equipment installed in the hydrogen tank which can survive or withstand the liquid hydrogen temperatures. The mission life for this facility is from 90 to 360 days. The animal research facility shares space with other experiments and the workshop.

The concept shown in Figure 5-7 includes cage facilities for 144 rats. One hundred and twelve cages are located in groups of 56 on both sides of the propellant utilization probe. Thirty-two other cages are located on 2 centrifuges, 16 on each. One centrifuge produces a 1/6-g simulated moon gravitational field and the other a 1-g Earth gravitational field for a group of experiment control animals. The environmental control system equipment and other cage systems support equipment is located along the propellant utilization probe. Three separate closed loop environmental control systems support the tank mounted and centrifuge mounted cages.

The facility would be partioned off into several areas. One area would separate the centrifuge from the remainder of the facility to prevent objects

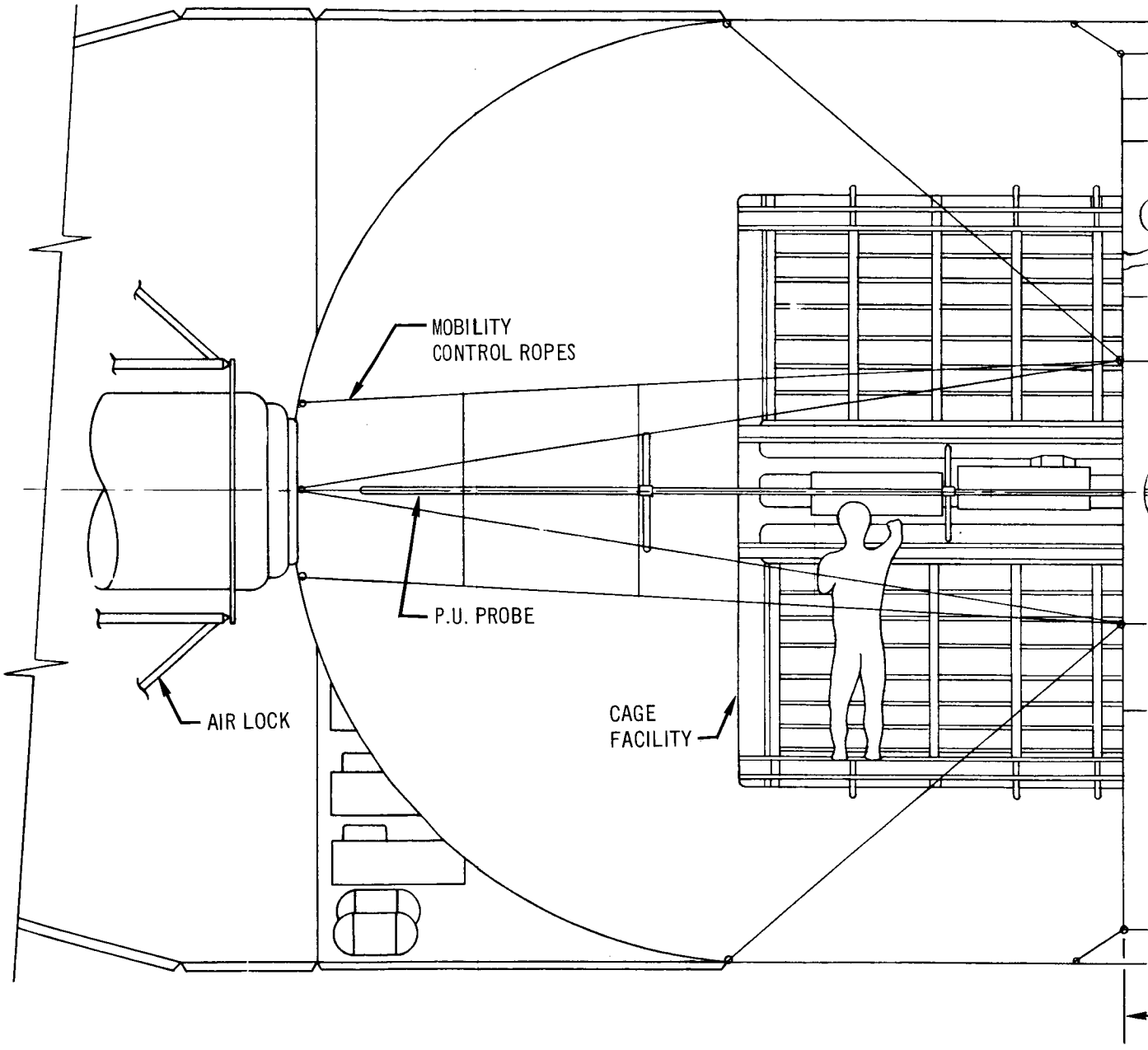

Figure 5-14. Centerline Elevation S-IVB Workshop

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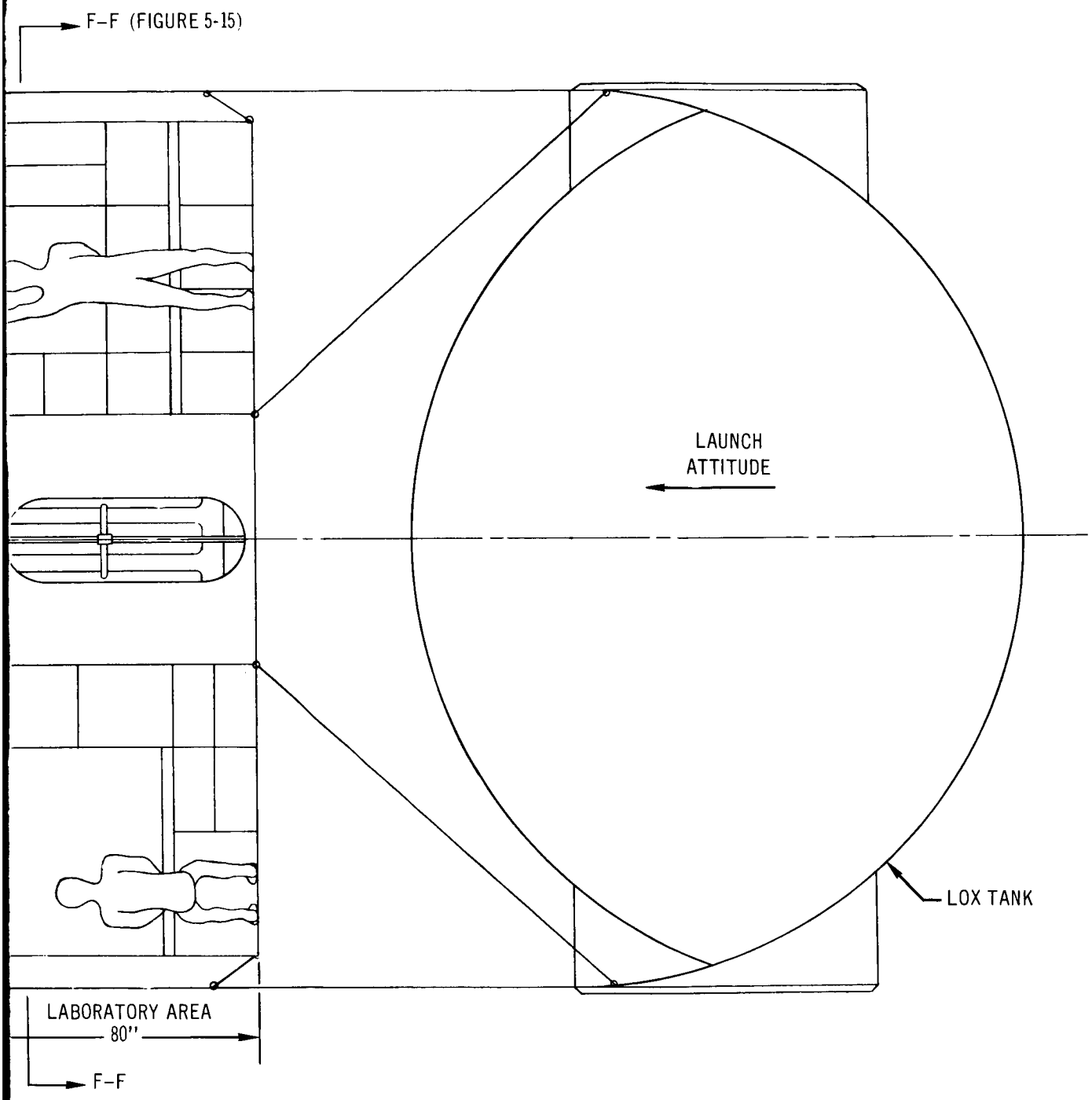

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and personnel from colliding with the rotating elements of the centrifuges. Another partition would be required for laboratory operations which may tend to contaminate the stage. These operations would include equipment cleaning and animal freezing. The general area surrounding the animal cages in the liquid hydrogen tank would also be partioned off, prevent contamination of the stage during animal handling and other operations in the cage area. A plan of the workshop laboratory area is shown in Figure 5-15. Figure 5-14 shows an elevation of the same area and shows the elevation of the facility without a centrifuge.

The lighting requirements for the facility would include elimination of the wall and centrifuge cage area as well as laboratory areas where technician functions would be carried out. Cage elimination would include diurnal simulation for the animal subjects. Crew mobility control and restraint device systems would be required for setting up and operating the cage and laboratory facility. The relatively large cage areas to be traversed by the attendant during setup and operation of the facility requires application of effective restraint devices. In fact the layout of the cage facility is governed considerably by the type of restraint devices employed. Two types of leg restraint devices are shown in Figure 5-7 and 5-14. In the cage area, foot restraints are employed as detailed in Figure 5-16. This concept incorporates foot restraint plates located approximately 6 ft apart along the edges of the cage areas on either side of the propellant utilization probe. The attendant can attach his feet by means of these devices to the restraint platforms on one edge of the cage facility and use the platforms on the opposite edge as handholds. In Figure 5-7 at the centrifuge control a more positive leg restraint concept is shown. Leg fittings which snap into brackets are utilized to lock the lower legs, but still allow freedom of upper body and arm movement. This concept is shown in detail in Figure 5-13.

5.1.3 S-IVB Stage Modifications

S-IVB stage modifications required for animal research installation in a workshop would be minimal. Additional attachments to the LH_2 tank wall may be required for cages and ECS equipment. The exact modifications would be determined after selection and design of a specific experiment program.

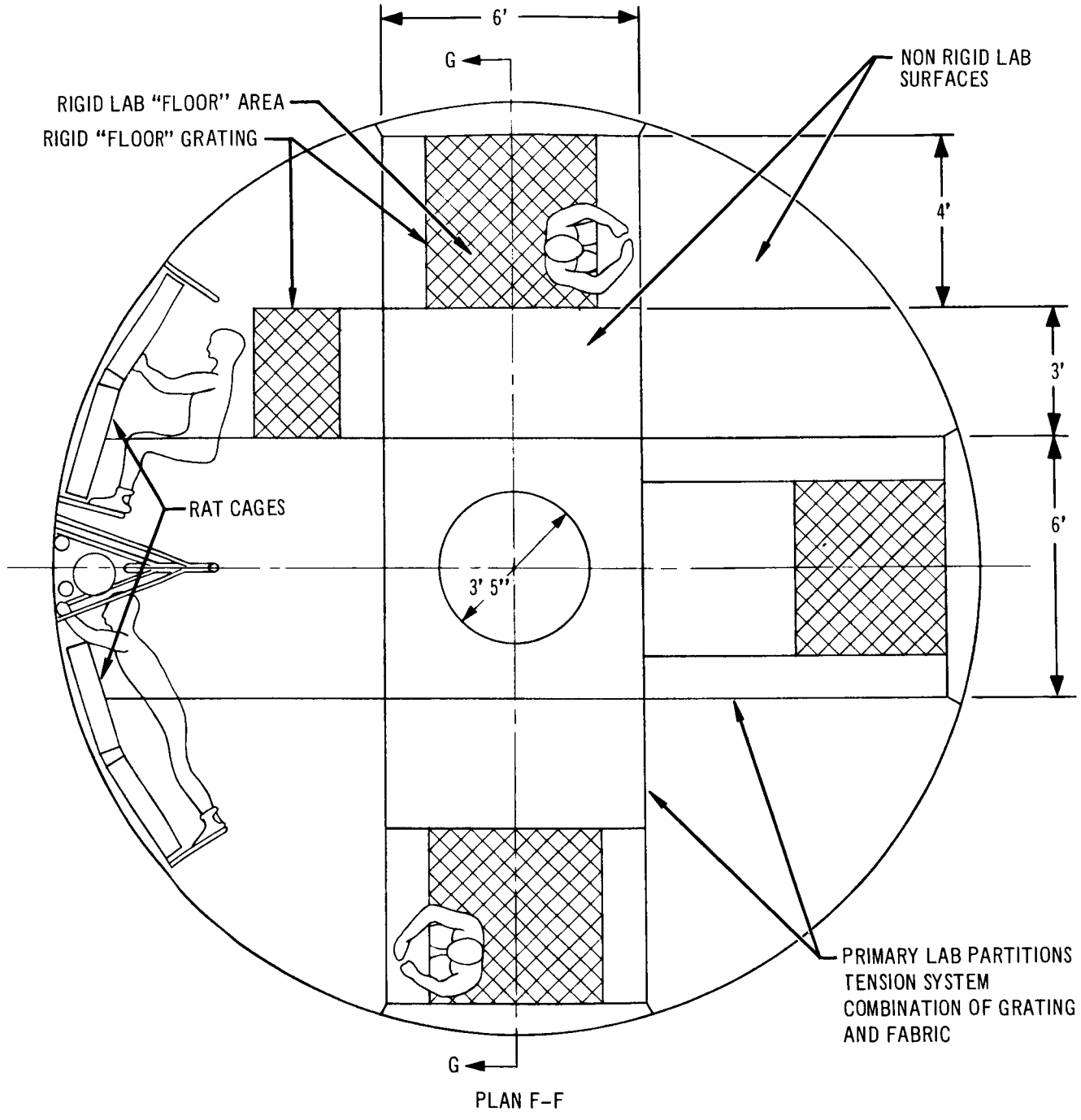


Figure 5-15. Plan F-F of Figure 5-14

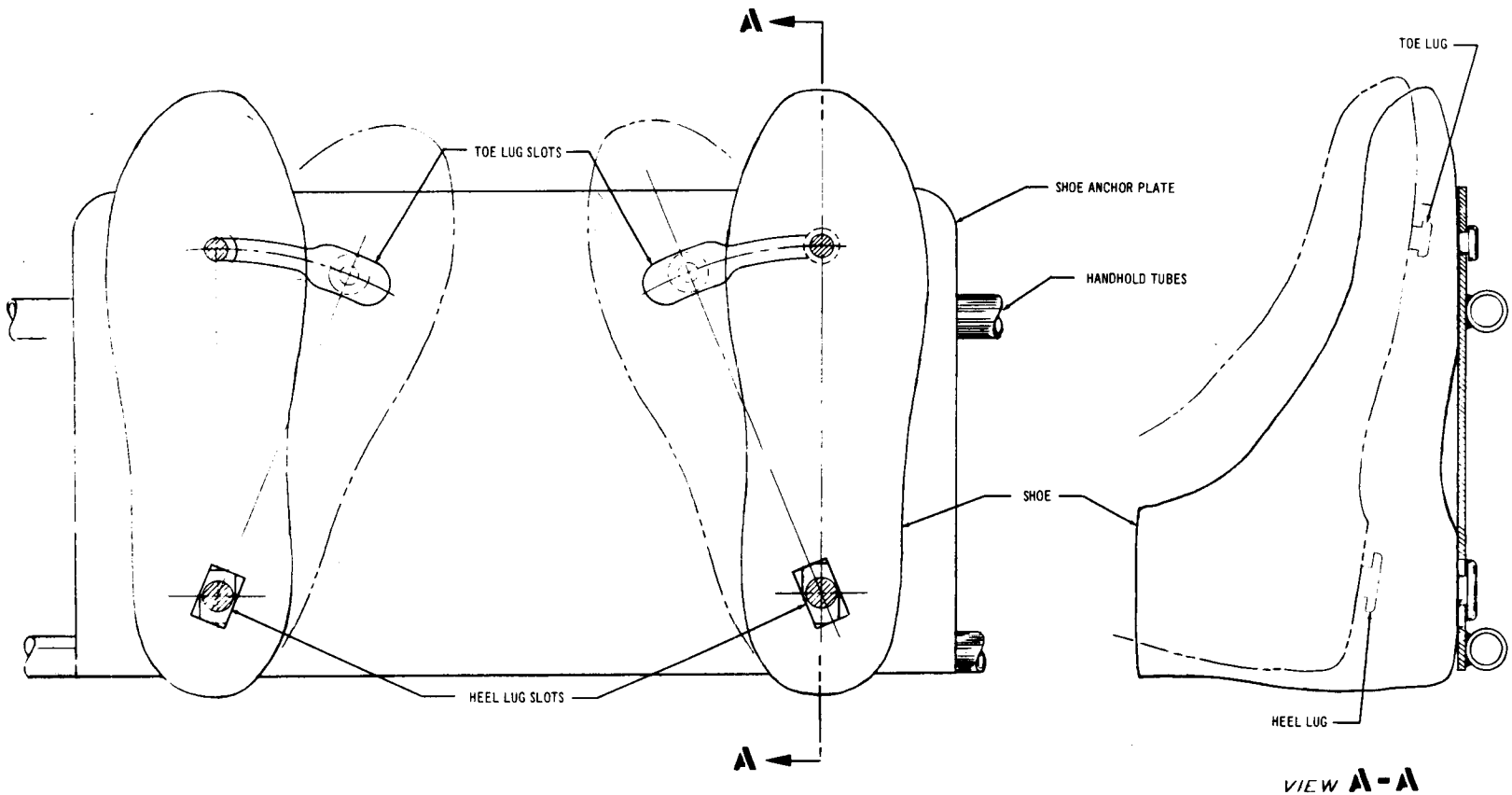


Figure 5-16. Foot Restraint Device Concept

5.2 LABORATORY IN THE PRE-LAUNCH MODIFIED S-IVB (EOSS)

The facilities provided by this version of a ground-equipped space station permit considerable flexibility in laboratory installations. Limitations imposed by the need to share the available volume will reduce the size of the facilities studied and described. Detailed design of equipment for a well-defined experiment program will lead to a more economical use of the volume.

5.2.1 Subsystem Requirements and Design Concepts

The subsystem designs discussed in this section for EOSS programs are not constrained by the weight limitations of the workshop missions. The designs proposed for workshop missions, in general, are directly applicable to these missions, without the necessity for prelaunch storage and setup.

5.2.1.1 Animal-Subject EC/LS System

The EC/LS requirements for the animal colony discussed in Section 2 are approximately equal to that of a human crew of 14 men; that is, a colony of 252 rats, 12 primates, and 6 swine consume the weight of food and oxygen that 14 men would require in orbit. Table 2-8 lists the life-support requirements for various animals. For missions longer than 30 days, it soon becomes apparent that the consumables involve large penalties to the launch and resupply vehicles. For example, the colony mentioned above requires 1,434 lb of oxygen, 1,855 lb of water and 1,647 lb of food for a 60-day mission. To absorb the output CO_2 and H_2O would require 1,441 lb of LiOH and 2,690 lb of LiCl if nonregenerable systems were used. Figures 5-17 and 5-18 illustrate the use of consumables versus mission time. It soon becomes obvious that regenerable systems should be used where existing technology permits when missions exceed 30 days. The EC/LS schematic shown in Figure 5-19 assumes a system involving CO_2 removal with a regenerable molecular sieve, and a water-vapor- and urine-recovery system. The various subsystems shown in the EC/LS schematic are discussed in the following paragraphs.

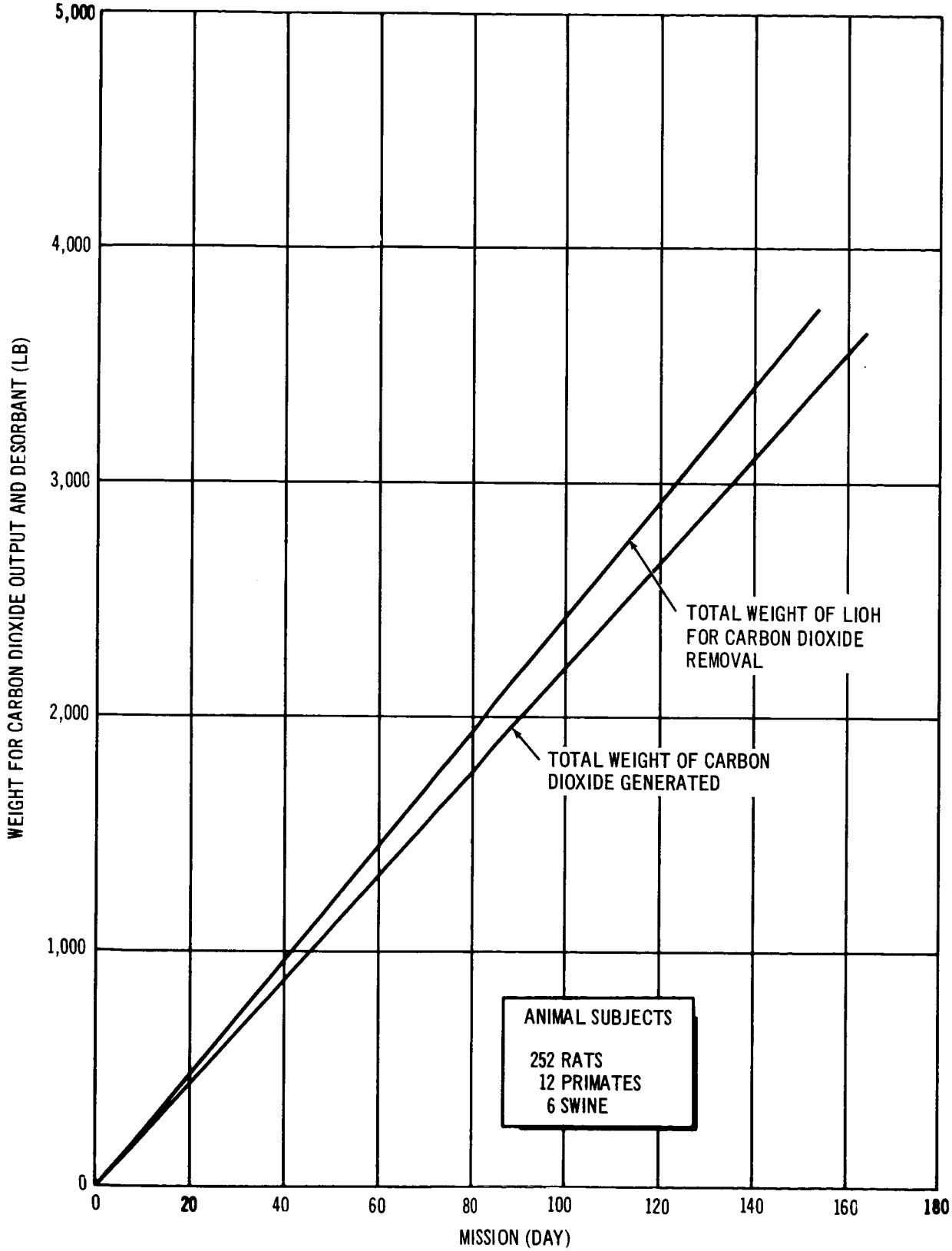


Figure 5-17. Outputs and Desorbants as a Function of Mission Days for a Nonregenerable System

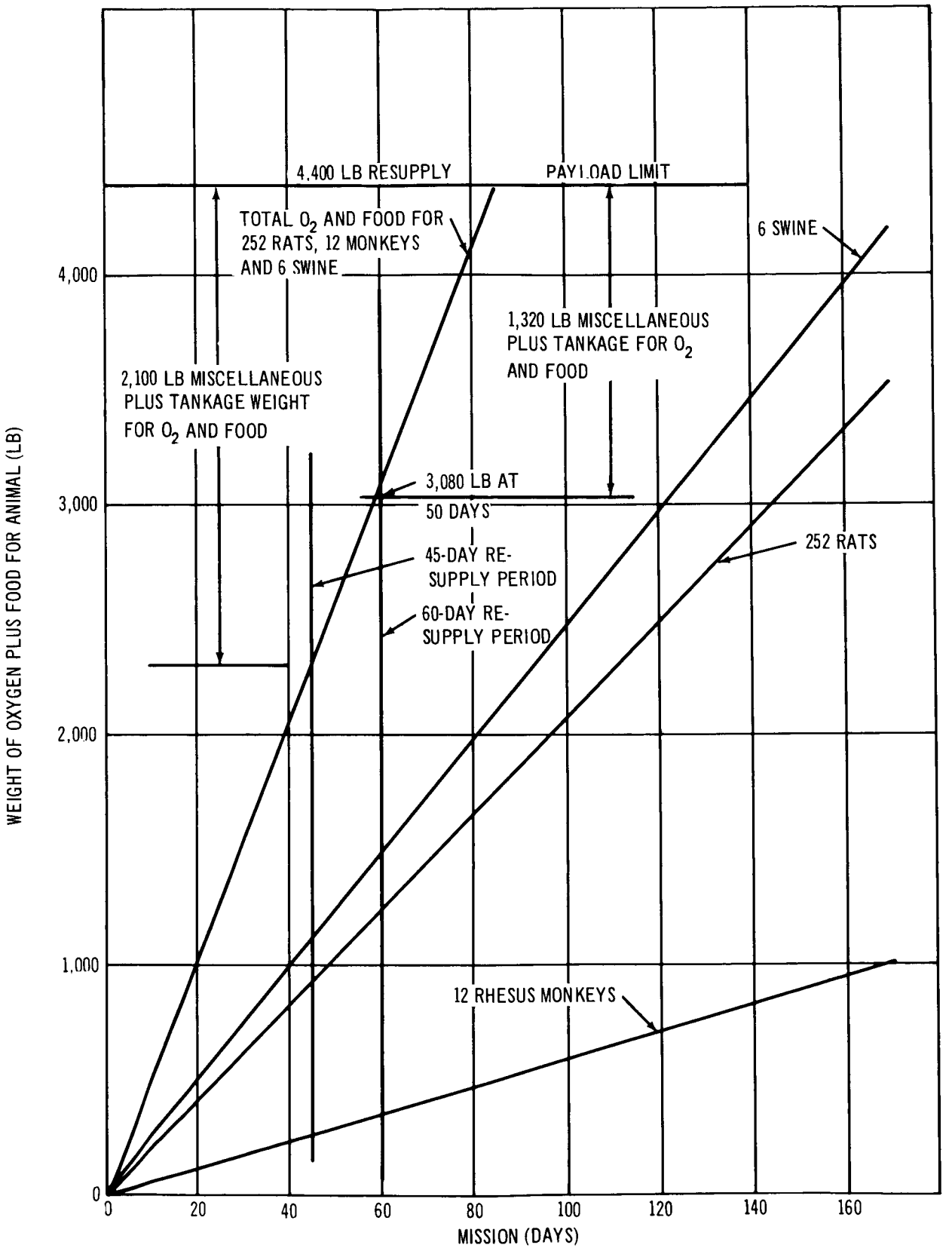
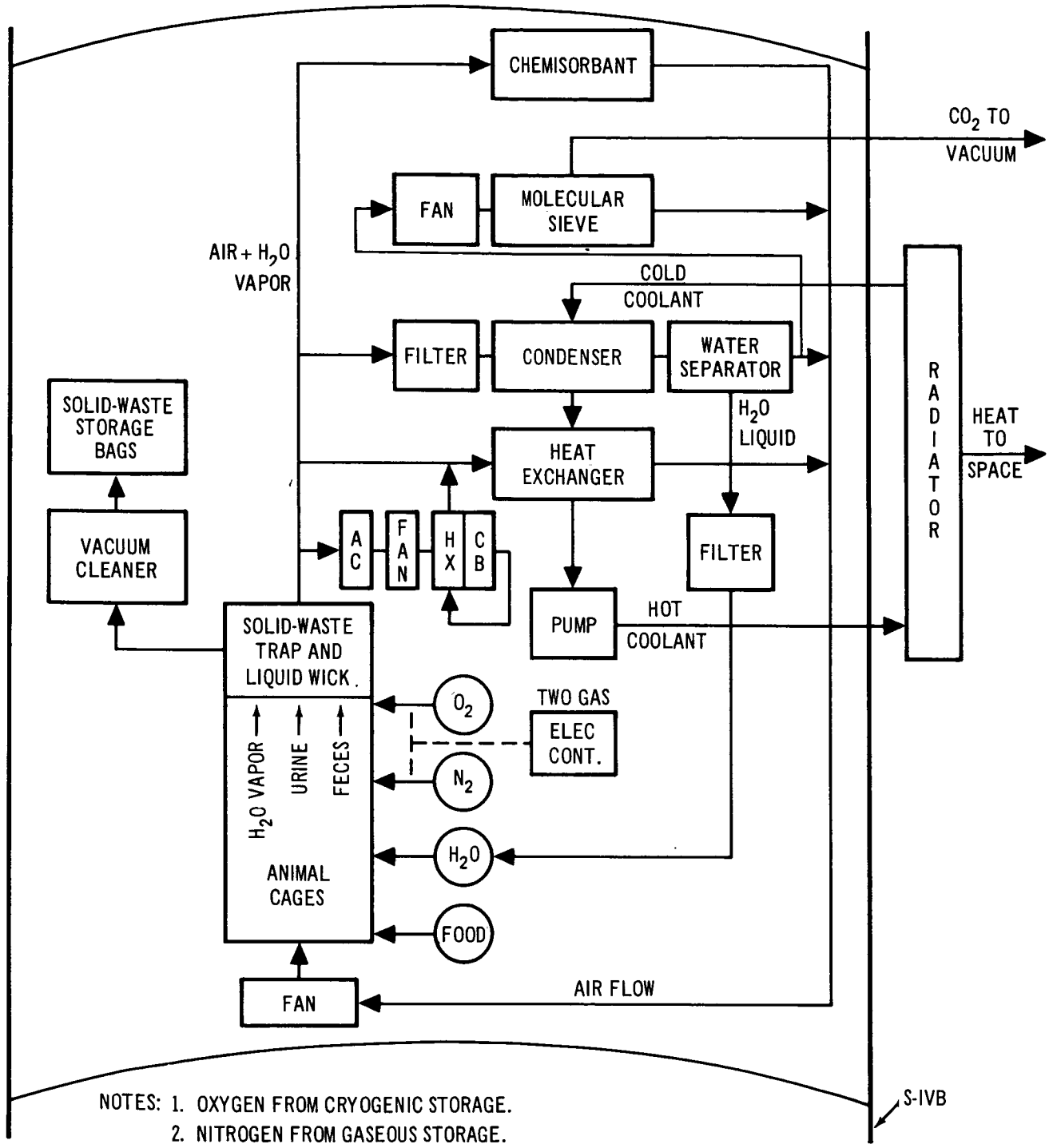


Figure 5-18. Dry Stage Oxygen and Food Requirements as a Function of Mission Days



NOTES:
1. OXYGEN FROM CRYOGENIC STORAGE.
2. NITROGEN FROM GASEOUS STORAGE.
3. WATER RECOVERED FROM URINE AND WATER VAPOR.
4. CATALYTIC BURNER (CB) REMOVES TRACE CONTAMINANTS BY CATALYTIC COMBUSTION.
5. CHEMISORBANT CANISTER REMOVES PARTICULATE MATTER AND CONTAMINANTS REMOVABLE WITH ACTIVATED CHARCOAL (AC)
6. MOLECULAR SIEVE ABSORBS CO_2 AND DESORBS TO SPACE.

Figure 5-19. Dry-Stage EC/LS Schematic

Radiator and Thermal Conditioning

The metabolic heat from the subject animal colony is about 6,000 Btu/hr and the electrical heat from EC/LS equipment should produce an additional 4,000 Btu/hr. Preliminary estimates indicate that it may be extremely difficult to reject this quantity of heat by radiation to the walls and conduction through the walls. Instead, a radiator and liquid coolant system are proposed for heat rejection from the vehicle. With this method, the vehicle walls can be highly insulated to avoid cold- or hot-wall problems, and the heat is transferred from the atmosphere to the radiator coolant by conventional air to liquid heat exchangers. The heat is then carried by the coolant to the radiator where it is dissipated to space by radiation. A liquid coolant also permits great flexibility in designing and arranging the ECS heat exchangers as well as permitting a closed-loop atmosphere system for the animal and human atmospheres. Presumably, the radiator could be a cylindrical shell around a portion of the outside of the S-IVB shell.

Two-Gas Pressure Control

A closed-loop ventilation system for the animal cages requires addition of oxygen into the cage atmosphere to maintain a minimum, oxygen partial pressure while oxygen is being consumed by the animals. The subject animal colony would consume 1,434 lb of oxygen in 60 days or approximately 1 lb per hour. An oxygen partial pressure sensor would control the 0_2 inflow, and a total pressure sensor would control the inert diluent gas inflow as necessary to make up for leakage. Presumably, nitrogen would be used as the diluent gas with a total pressure equal to that in the laboratory. Oxygen partial pressure would be approximately 3.5 psia.

The 1,434 lb of oxygen required for 60 days would require two 45-in. diam spherical tanks of gaseous oxygen at 5,000 psia with the two tank weights approximately equal to 3,000 lb. With supercritical cryogenic storage of oxygen, tankage weight could be reduced to about 1,600 lb. It appears that a cryogenic storage system is the most practical from a volume and a tank weight standpoint when resupply and initial launch weight factors are considered.

An electronic controller is required for the two-gas control system to convert the oxygen partial and total pressure signals to control functions which will operate the inflow valves.

Humidity Control

Water is removed from the circulating atmosphere by cooling some of the air in a condenser below its dewpoint which causes the water vapor to condense into fine droplets. The liquid droplets can then be removed from the atmosphere by a centrifugal water separator. The humidity in the atmosphere is controlled by selecting the quantity of the bypass flow passing through the condenser, and the lower limit is established by the lowest coolant temperature from the radiator. A coolant temperature of $40^{\circ}F$ is a practical one which is sufficiently above $32^{\circ}F$, to avoid freezing problems in the condenser. A relative humidity of 50% can easily be maintained with this type of humidity control system.

Water Recovery

A regenerable water-recovery system appears to be necessary for the subject animal colony because of the large amount of water required. As mentioned above, 1,855 lb of water would be consumed in 60 days, and this amount would have to be resupplied in this period. Water recovery with the proposed closed-loop system can be quite easily achieved because the waste trap exists and operates as an air evaporator, and the condenser converts the vapor to liquid again. It merely remains to add a suitable filter and processing canister to make the waste condensate suitable for reuse in the animal water-supply system. A bacteria inhibitor would be used on the waste-trap liquid-evaporator wicking as well as in the water-recovery filter. With this type of system, the initial water supply should last for the entire mission with resupply water replacing leakage loss and some water loss in the feces only. These losses would be small in comparison to that involved without a water-recovery system.

Carbon-Dioxide Removal

Carbon-dioxide removal from the atmosphere involves similar problems to that of humidity with respect to regenerable versus nonregenerable

considerations. Use of a nonregenerable CO_2 absorbant like lithium hydroxide would require 1,441 lb of LiOH every 60 days. From a resupply standpoint, this quantity is excessive. A molecular sieve with a regenerable synthetic zeolite as the absorbent with desorption to vacuum can minimize the resupply requirements. The mechanical equipment required for a molecular sieve would weigh less than the LiOH absorbant, and it could be used for long periods with minimum resupply requirements.

Trace Contaminant Control

A catalytic burner is included in the EC/LS system in a similar manner to that used in the wet-stage configuration. The discussion on the catalytic burner that appears earlier in Section 5 applies to the dry-stage configuration as well.

Waste Management

The waste-management system for the dry stage could be the same as that for the wet stage. That is, air motion would be used to sweep the cages clear of feces and debris along with the urine. Waste pads collect and retain the solid material while evaporating the urine and excess moisture from the feces. It is expected that the feces could be dried sufficiently to prevent excessive decomposition before periodic removal with a vacuum cleaner and storage in sealed bags. Preliminary estimates indicate that the waste pads could hold the waste accumulated over a period of 30 to 60 days before it would start clogging the airflow path in the waste pads. A replaceable pad could be used while used pads were being cleaned and reprocessed.

Animal Life-Support Requirements

Table 2-8 gives the life-support requirements for the animals considered in this study. It was necessary to calculate much of the data on metabolic parameters because experimental data on such things as metabolic heat and water output seem to be lacking. A reasonable approach to obtaining parametric metabolic data involves using mathematical equations to describe heat output, O_2 consumption, CO_2 generation, metabolic water output, and solids output as a function of the diet. Once a diet and amount of food consumed is

established, all of the above parameters can be calculated. The equations used are those given on page 197 of Reference 7. These equations were derived for use with human beings, but it was considered that they would apply to animals as well. Possibly some error would be involved if the types of protein, fat, and carbohydrate were much different for animal food than food for man. Where data for animals did exist, the equations gave very reasonable answers. The equations are as follows:

$$H = 4.182\ C + 9.461\ F + 4.316\ P \text{ kcal/unit time}$$

$$O_2 = 0.829\ C + 2.019\ F + 9.967\ P \text{ liters/unit time}$$

$$CO_2 = 9.829\ C + 1.427\ F + 0.775\ P \text{ liters/unit time}$$

$$W = 0.555\ C + 1.071\ F + 0.413\ P \text{ grams/unit time}$$

where

H = metabolic heat/unit time

C = carbohydrate metabolized in grams/unit time

F = fat metabolized in grams/unit time

P = protein metabolized in grams/unit time

W = metabolic water generated in grams/unit time

The assumptions used in deriving the equations are: (1) all food used is carbohydrate, fat or protein, each of which is characterized accurately enough by a single set of average properties; and (2) all foods are reduced to standard end products, namely carbon dioxide, water, and urinary nitrogen. From the equations, one may predict for any given mixture of carbohydrates, fat, and protein the heat (energy) produced, the oxygen consumed, and the carbon dioxide, water, and urinary nitrogen excreted.

Various library references were used to establish the type of diet and quantity of food required by the animals. The metabolic parameters were then calculated by the above equations.

One additional parameter was required from an EC/LS engineering standpoint. This quantity is the amount of solid material excreted by the animals. The equation describing this quantity was derived as follows:

$$\text{inputs} = \text{outputs}$$

$$\text{food} + B + H_2O + O_2 = CO_2 + H_2O + W + \text{waste}$$

where

B = indigestible solids

H_2O = water input

Food = C + F + P

Waste = dry feces + urinary solids + remaining body waste solids

Because O_2, CO_2, and W are all functions of carbohydrates (C), fat (F), and protein (P), the waste is also a function of the food; the resulting equation for the solid waste output reduces to

$$\text{waste} = B + 0.43\ P$$

This result was obtained by assuming that the assimilation of the food was 100% efficient. Apparently, if this assumption is made, the carbohydrate and fat are reduced to CO_2, water, and proteins and the indigestible solids are the only contributors to the feces and remaining solid output. If efficiency factors are used to express the assimilation of the carbohydrates, fats, and proteins, the equation for the waste solids output is

$$\text{waste} = B + (1-\eta_C)\ C_2 + (1-\eta_F)\ F + (1-0.55\eta_P)$$

For η_C = 0.95 estimated value

η_F = 0.95 estimated value

η_P = 0.93 estimated value

Waste = B + 0.05 C + 0.05 F + 0.489 P

This equation can be used to estimate the amount of solid deposit that the waste traps would collect when the diet is specified. For the rat, it was calculated that the solid waste deposited on the waste pad would be 1/32 in. thick at the end of 60 days.

5.2.1.2 Electrical Power Requirements

Because of the similarity of the experiment program described for EOSS to the long-term workshop program, the power requirements are essentially those shown in Table 5-2 in Section 5.1.1.2, that is, 375 W continuous load. More elaborate laboratory equipment will be available in an EOSS configuration, and short-term loads of up to 100 W may be expected when this equipment is in use. No regulation requirements beyond those normally provided by the space-station electrical-power supply have been identified.

5.2.1.3 Data Requirements

The basic data system discussed in Section 5.1.1.3 will meet the requirement for the experiment program for an EOSS mission. The number of measurements required on both equipment and animals will increase because of the increased scope of experiments, but these increases can easily be absorbed. The large increase in written observations, however, will require a system which will permit translation of this information into a form which can be quickly transmitted to Earth.

5.2.2 S-IVB EOSS Installations

An animal research facility in an EOSS would differ radically from one in a workshop configuration for two reasons. The facility weight in an EOSS is virtually unrestricted and the station, being nonpropulsive, can be ground-fitted, checked out, and operational at launch. In addition, an EOSS could be resupplied periodically, perhaps every 30 to 60 days, making possible long-duration experiments on large animal populations. Facility concepts are presented for possible program durations of from 90 to 360 days involving animal populations such as 252 rats, 12 rhesus monkeys, and 6 minature swine. The total estimated weight of an animal facility of this size with expendables for 60 days of operation is approximately 13,000 lb. A facility weight breakdown is shown in Table 5-4.

Table 5-4

EOSS ANIMAL FACILITY WEIGHT

Items		Animal Facility Weights* (lbs) Expendable Volumes (cu ft) 300 Rats**	12 Monkeys	6 Swine	Weight Totals (lb)
Animal weight (lb)		160	80	720	960
Cage facility weight (lb)		600	150	250	1,000
Oxygen	Weight (lb)	1,000	400	850	2,250
	Volume (cu ft)	22	13	28	
Water	Weight (lb)	1,300	450	2,000	3,750
	Volume (cu ft)	16	7	33	
Food	Weight (lb)	800	200	1,400	2,400
	Volume (cu ft)	20	5	36	
Lithium hydroxide	Weight (lb)	800	250	1,500	2,550
	Volume (cu ft)	13	4	24	
Weight totals (lb)		4,660	1,530	6,720	12,910

*Cage facility weight includes ducting, ECS hardware and the cage support structure.

**Nominal population.

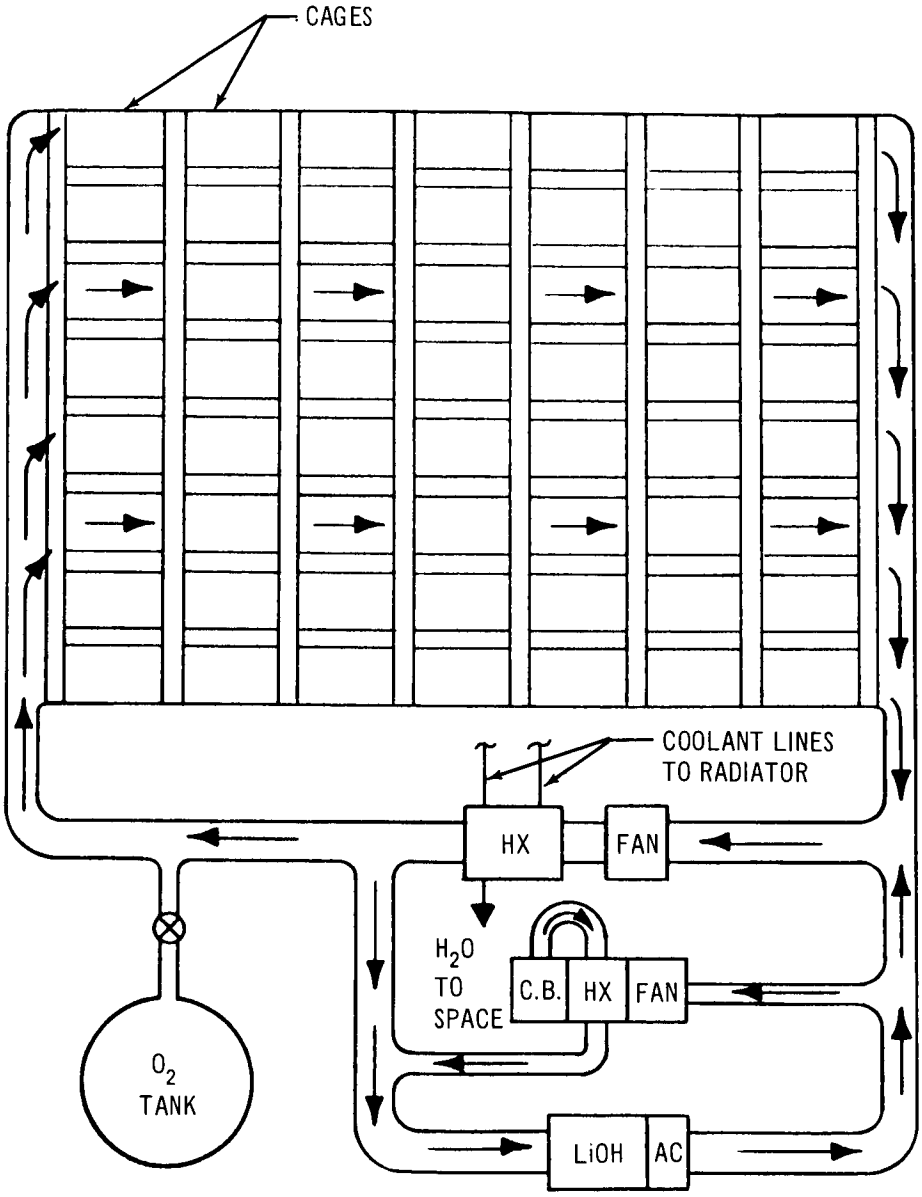
The animal cage ECS for this facility would be closed looped with air-tight, negatively pressurized cages operating at approximately 1 in. H_2O negative pressure with respect to the facility pressure. A typical ECS schematic is shown in Figure 5-20. The figure shows a nonregenerative LiOH CO_2 removal system for illustrative purposes. Alternately, the use of a molecular sieve for CO_2 removal, and the water recovery system shown in Figure 5-19, would provide a weight reduction for long-duration missions.

Two EOSS animal-facility layouts are presented. Figures 5-21 and 5-22 illustrate an animal research facility housed in a portion of the S-IVB hydrogen tank. Figures 5-23 and 5-24 depict a facility housed in the S-IVB liquid oxygen tank.

5. 2. 2. 1 Hydrogen Tank Facility Concept

The hydrogen tank facility (Figure 5-21) is composed of an animal-facility bay, a laboratory bay, and a centriguge bay, all operating with an atmospheric pressure in the 5- to 7-psia range. The animal-facility bay (Plan C-C, Figure 5-22) has an 84-in. net "floor" to "ceiling" height, has a 258 in. diam and a volume of 2, 500 cu ft. The cages are mounted on the "floor" (launch attitude) and the supporting semi closed-looped ECS equipment is located on the opposing surface or bay "ceiling". This facility as shown would house an animal population of approximately 252 rats, 12 monkeys, and 6 swine. Cage sizes would be 5 in. x 7 in. x 18 in. for rats, 15 in. x 15 in. x 24 in. for monkeys (rhesus and 36 in. x 48 in. x 30 in. for swine. Platforms which serve as a combination foot restraint and hand hold are located across the cage and in ECS equipment areas on 6-ft centers. Foot- and leg-restraint system hardware as described in Section 5. 1. 1. 1. 9 formed part of the basis for the cage layout shown.

The laboratory bay (Plan B-B, Figure 5-22) has similar dimensions and is approximately 50% occupied by animal-research-facility laboratory equipment. The laboratory bay (Plan C-C, Figure 5-22) is divided into eight compartments of approximately 285 cu ft each. Three of these, the dry and wet lab and the centrifuge control station, are peculiar to the animal-research facility. The remaining compartments are shared with other space-station activities in life science and physical science experiment programs.



NOTE: REFER TO FIGURE 5-19 FOR SCHEMATIC OF LONG DURATION MISSION EC/LS SYSTEMS WITH REGENERATIVE MOLECULAR SIEVE AND WATER RECOVERY

Figure 5-20. Animal-Cage Facility, Environmental-Control System for Long-Duration Mission

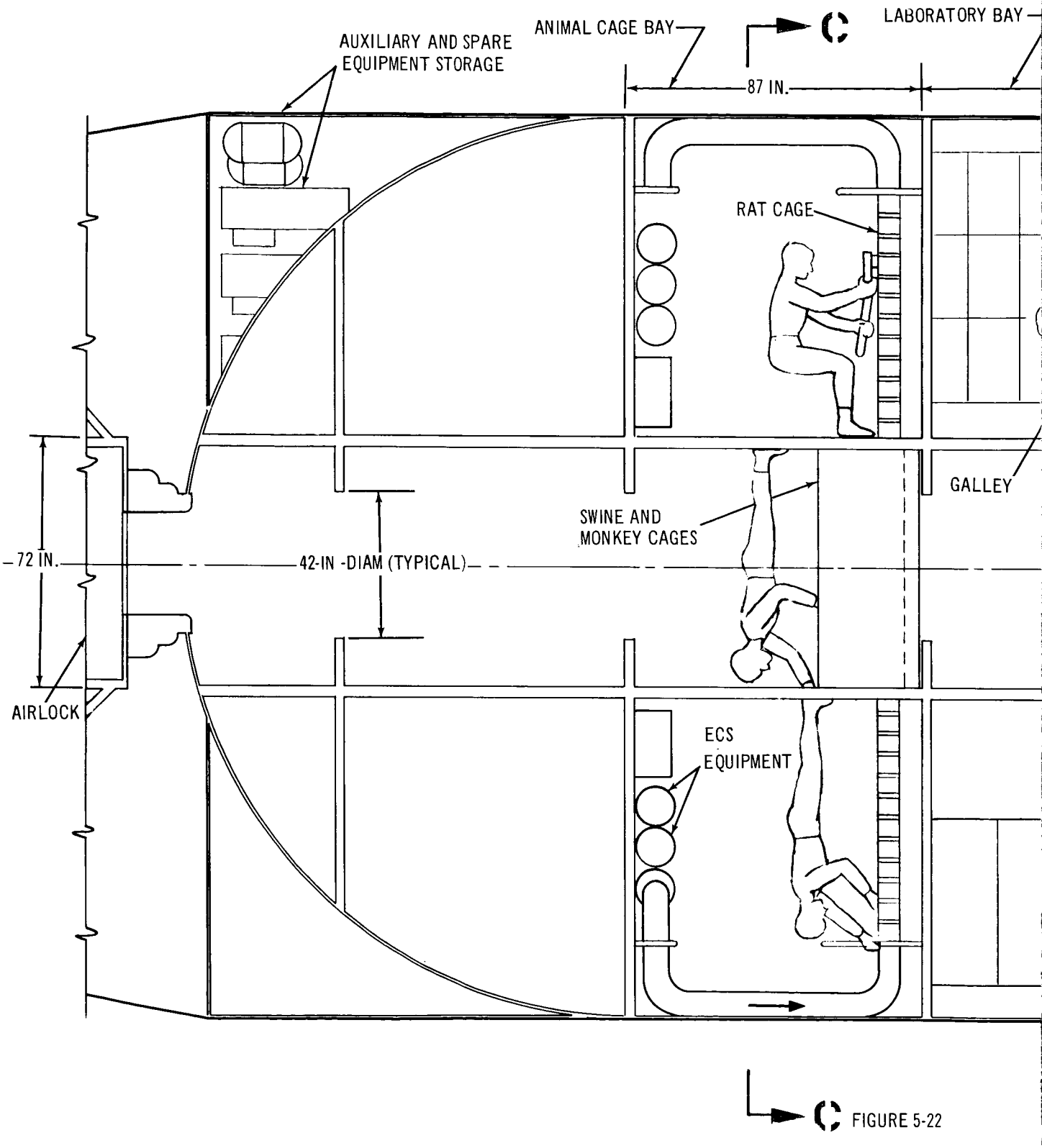


FIGURE 5-22

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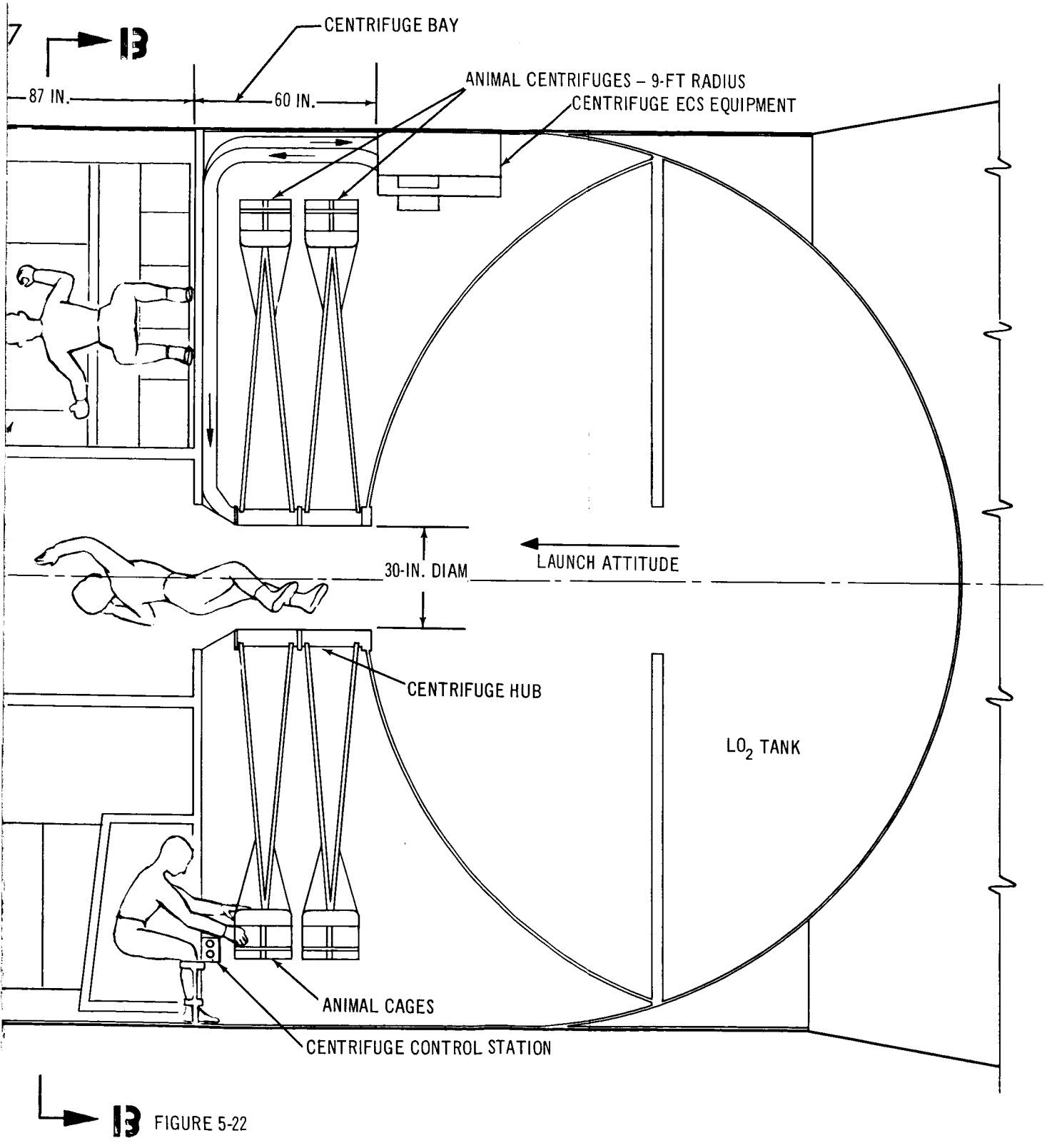

Figure 5-21. Elevation – S-IVB Prelaunch Modified Laboratory Configuration (EOSS)

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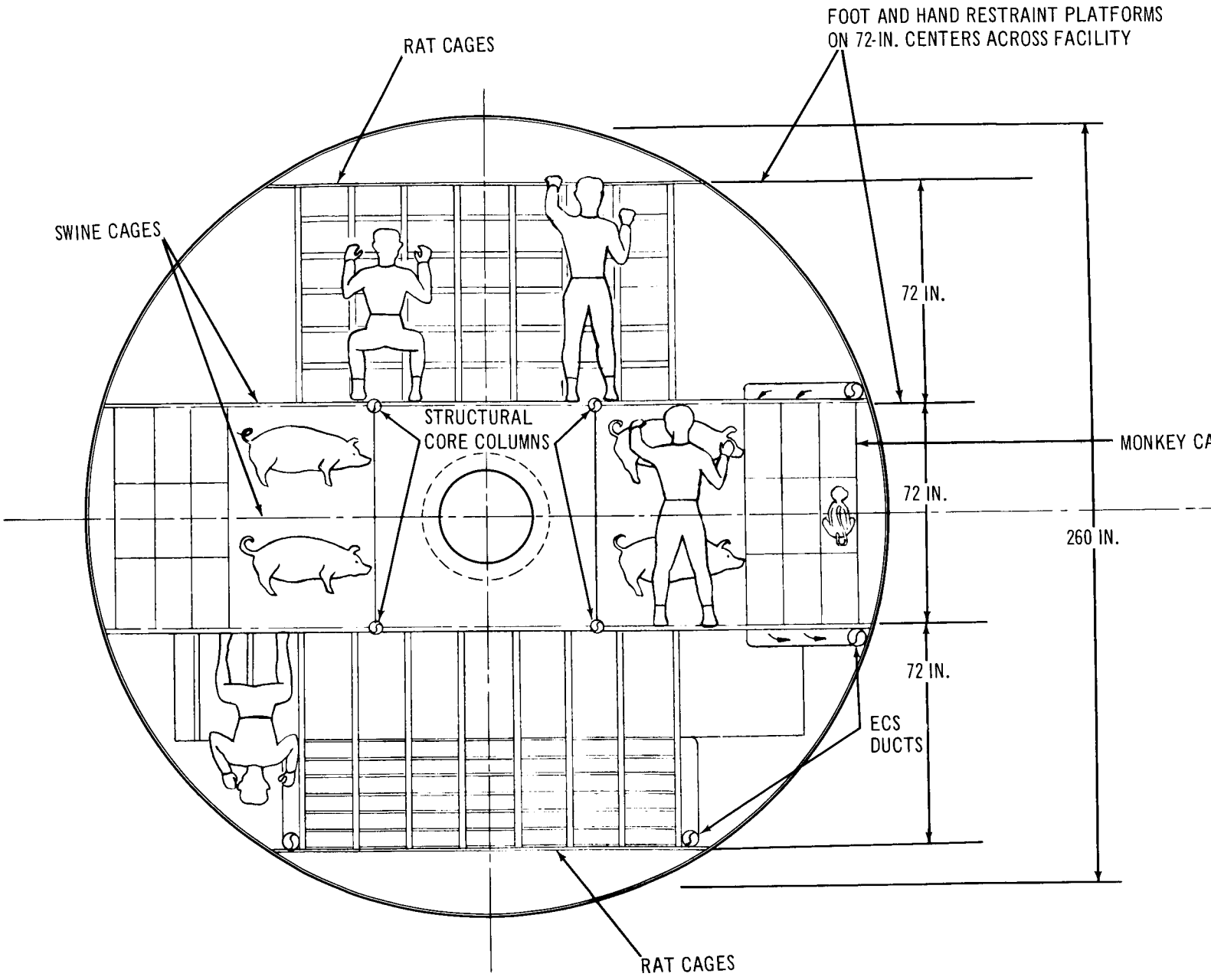
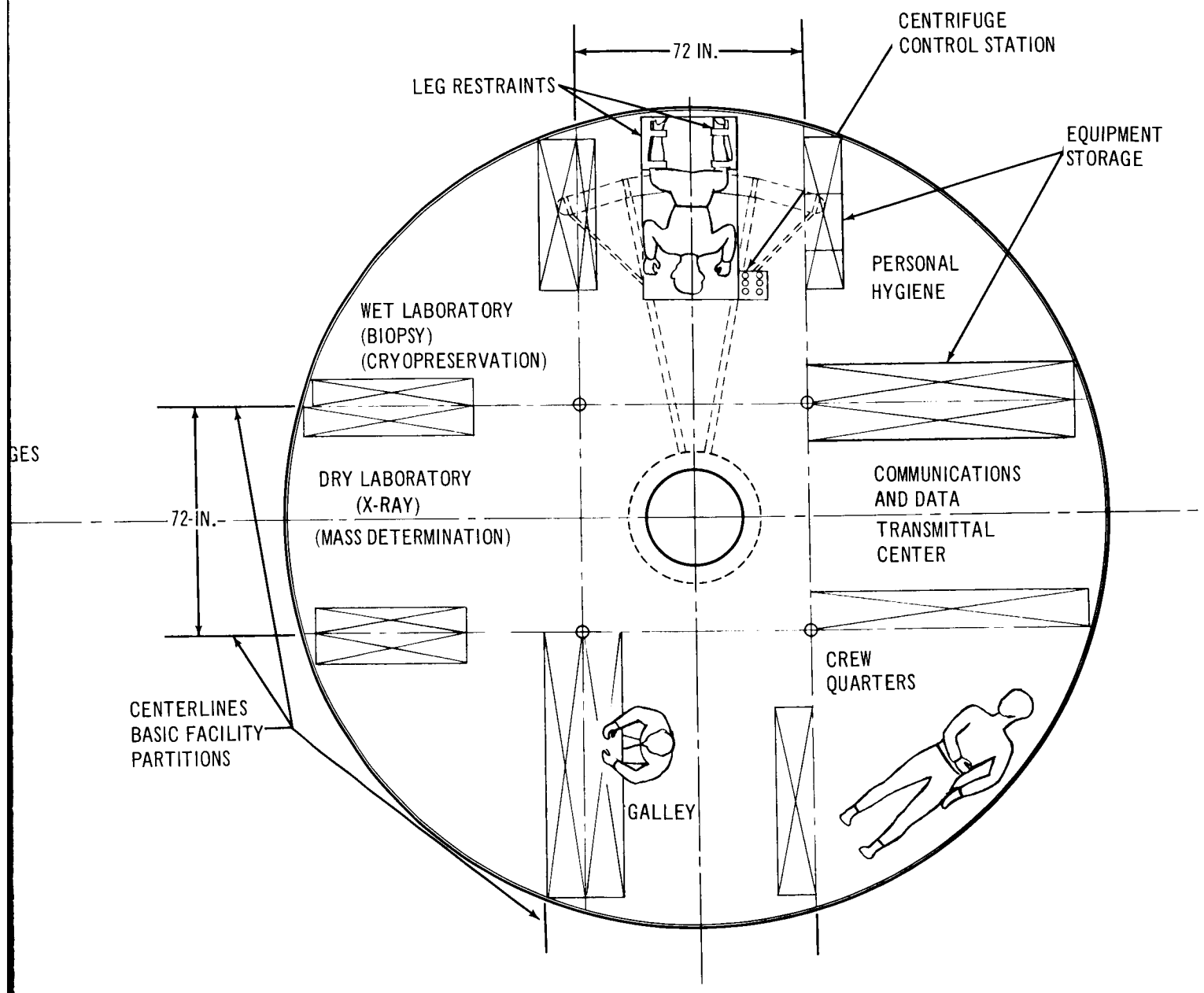
121 B

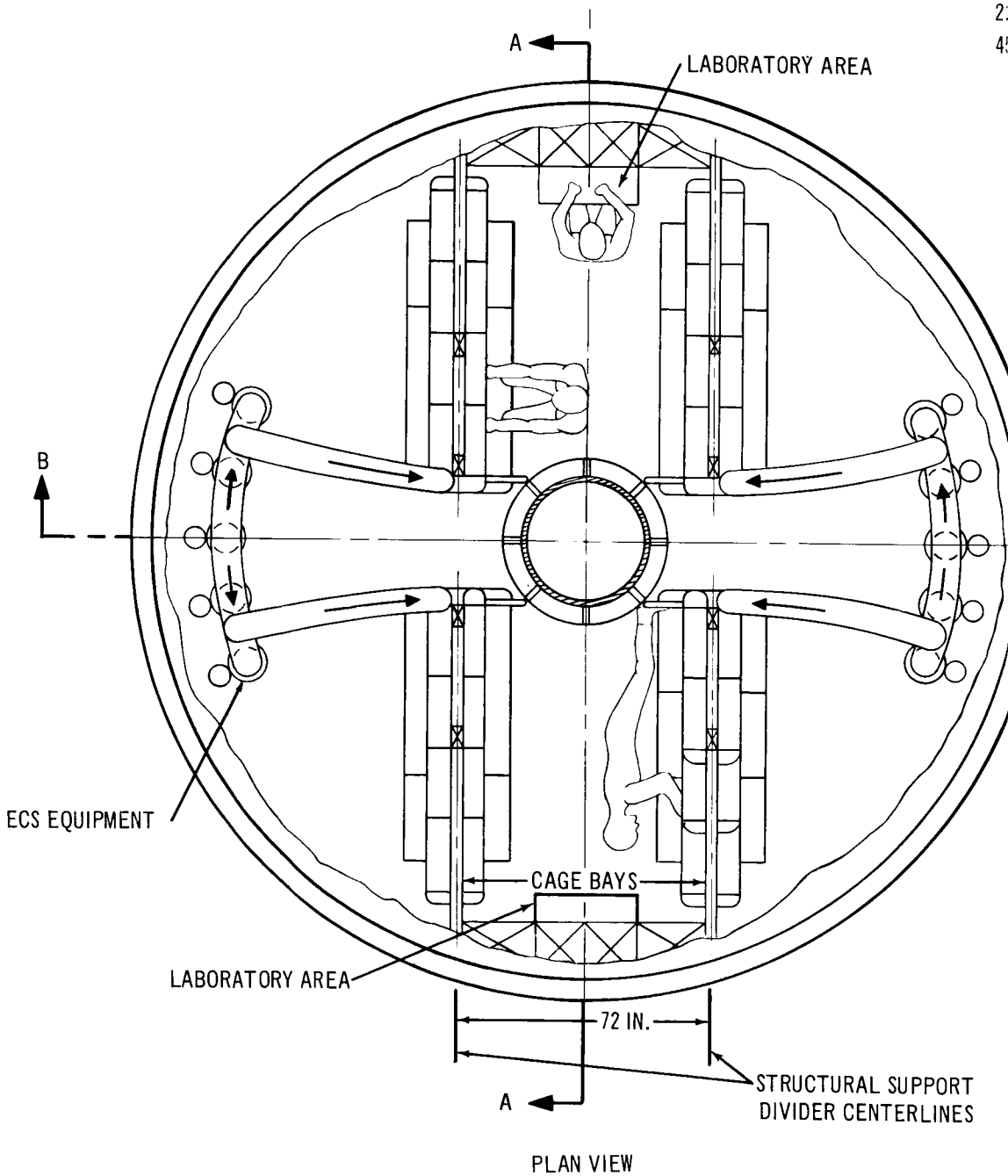


PLAN C-C

Figure 5-22. Plan Views of Figure 5-21


72 IN.
CENTRIFUGE
CONTROL STATION
LEG RESTRAINTS
EQUIPMENT
STORAGE
PERSONAL
HYGIENE
WET LABORATORY
(BIOPSY)
(CRYOPRESERVATION)
DRY LABORATORY
(X-RAY)
(MASS DETERMINATION)
72-IN.
COMMUNICATIONS
AND DATA
TRANSMITTAL
CENTER
CREW
QUARTERS
CENTERLINES
BASIC FACILITY
PARTITIONS
GALLEY

PLAN B-B



PLAN VIEW

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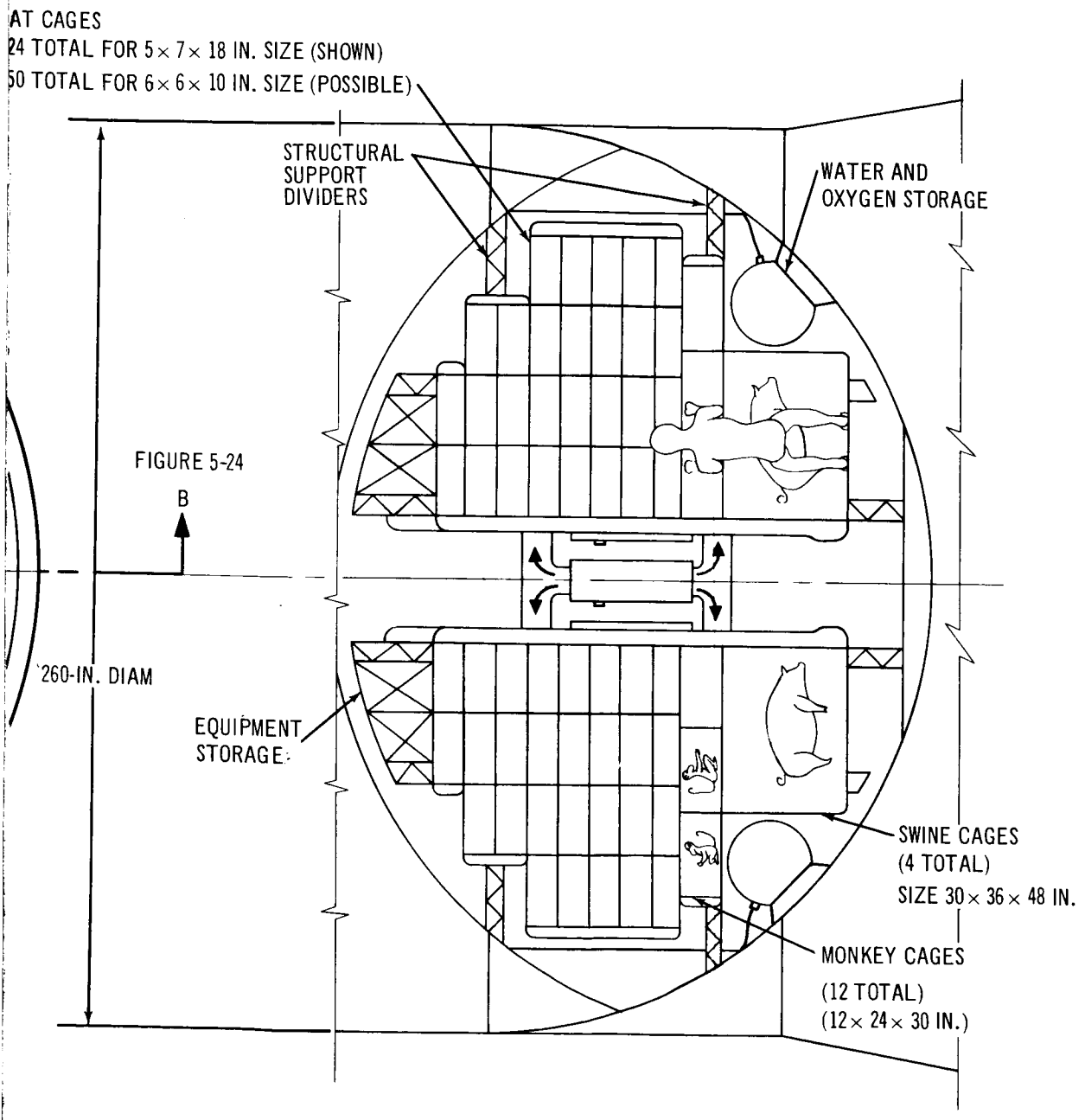

ELEVATION A-A

Figure 5-23. S-IVB LO_2 Tank Animal Facility

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123B

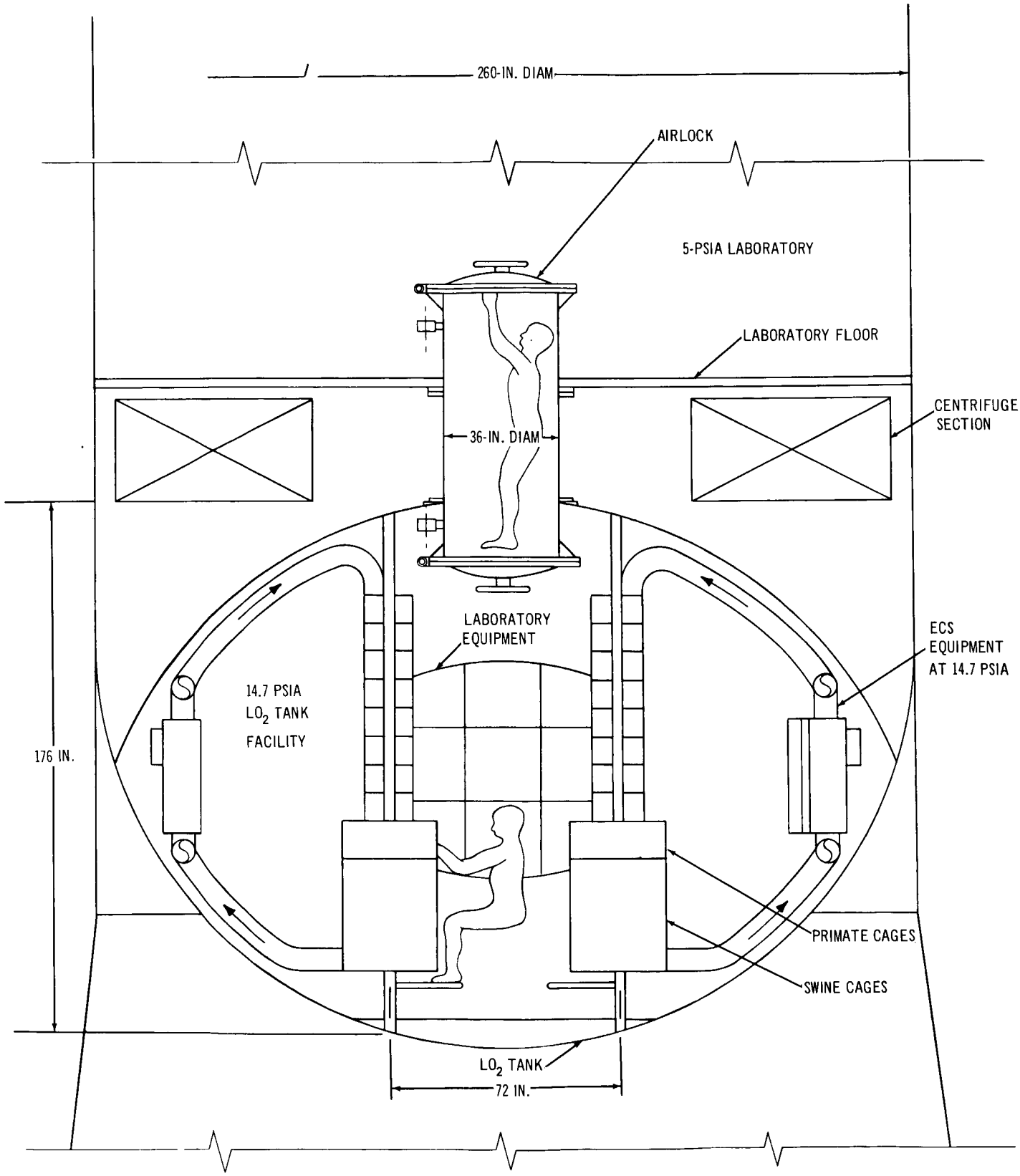

Figure 5-24. Elevation B-B (Figure 5-23) S-IVB LO_2 Tank Animal Facility

The centrifuge shown is an animal centrifuge similar to that described in Section 5.1.1.4 but has an open hub. It could house 32 rats in 1/6-g and 1-G gravitational fields in two counterrotating elements.

5.2.2.2 Liquid Oxygen Tank Facility Concept

An alternate concept of an EOSS animal-research facility located in the S-IVB liquid oxygen tank is shown in Figures 5-23 and 5-24. The liquid oxygen tank can, with an airlock, be utilized to conveniently house an animal facility at pressures up to 14.7 psia, independent of the pressure in the balanc of the station. The liquid oxygen tank has a volume of 2,828 cu ft and, as utilized here, could house in four bays 200 to 300 rats, 12 monkeys, and 4 swine. The facility would include closed-looped cages, ECS equipment, expendable storage, and two technician work areas.

5.3 SEPARATE MODULE CONCEPTS

The scope of the experiment program for each separate module concept is constrained primarily by the volume available to house animal subjects. Representative animal-facility concepts are presented for the LEM-Lab in Figure 5-25, for the refurbished command module in Figure 5-26, and for the powerhouse module in Figure 5-27. These concepts are based on the following assumptions:

1. The modules and their cage facilities would operate at the same atmospheric pressure as the space station, which is expected to be in the 5 to 7 psia pressure range for an EOSS.
2. The modules will not have their own docking capability and would be docked by another vehicle such as a command module.
3. The module ECS is separate from the animal-cage ECS and partially or entirely supported by the space station.
4. Power for the facility will be supplied by the space station.
5. The facility will store expendables for 30 days of operation without resupply.

Table 5-5 lists the weight of the animal-facility components for the different quantities and types of animals housed in the three module layouts. Table 5-6 lists the volume and total weight of the animal facility in the three modules.

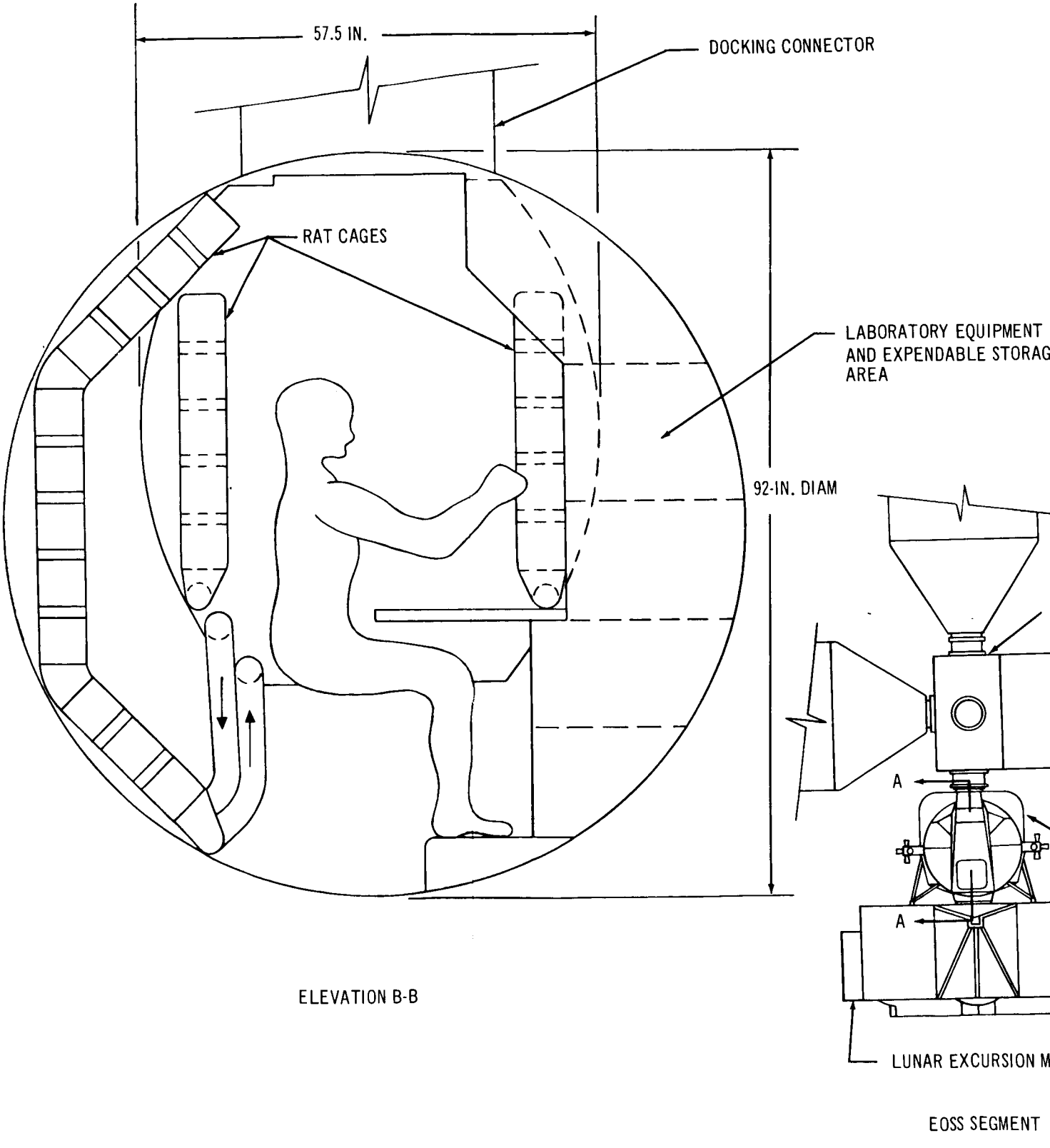

Figure 5-25. LEM-Laboratory Animal Facility Layout (Volume 250 cu ft)

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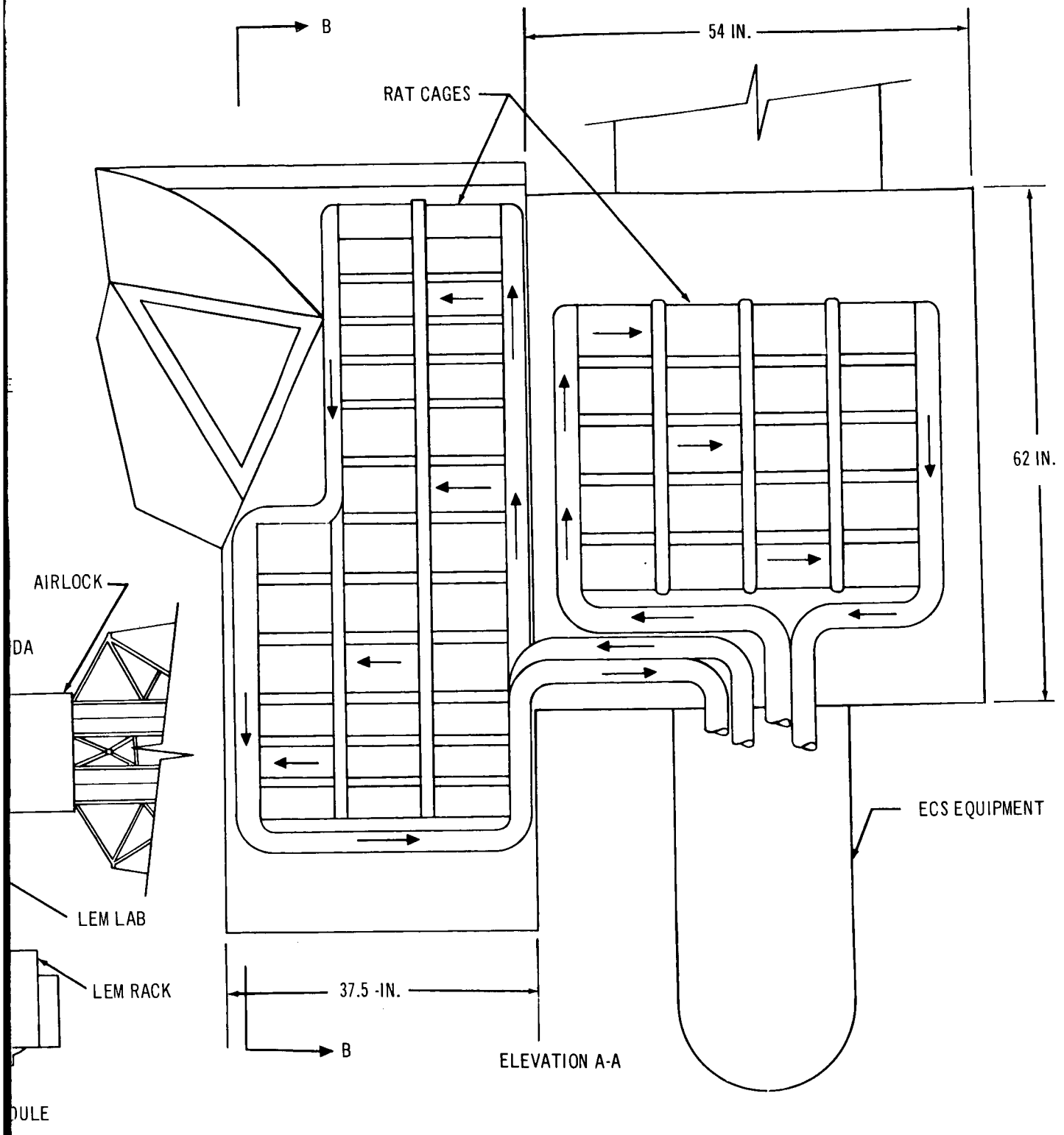

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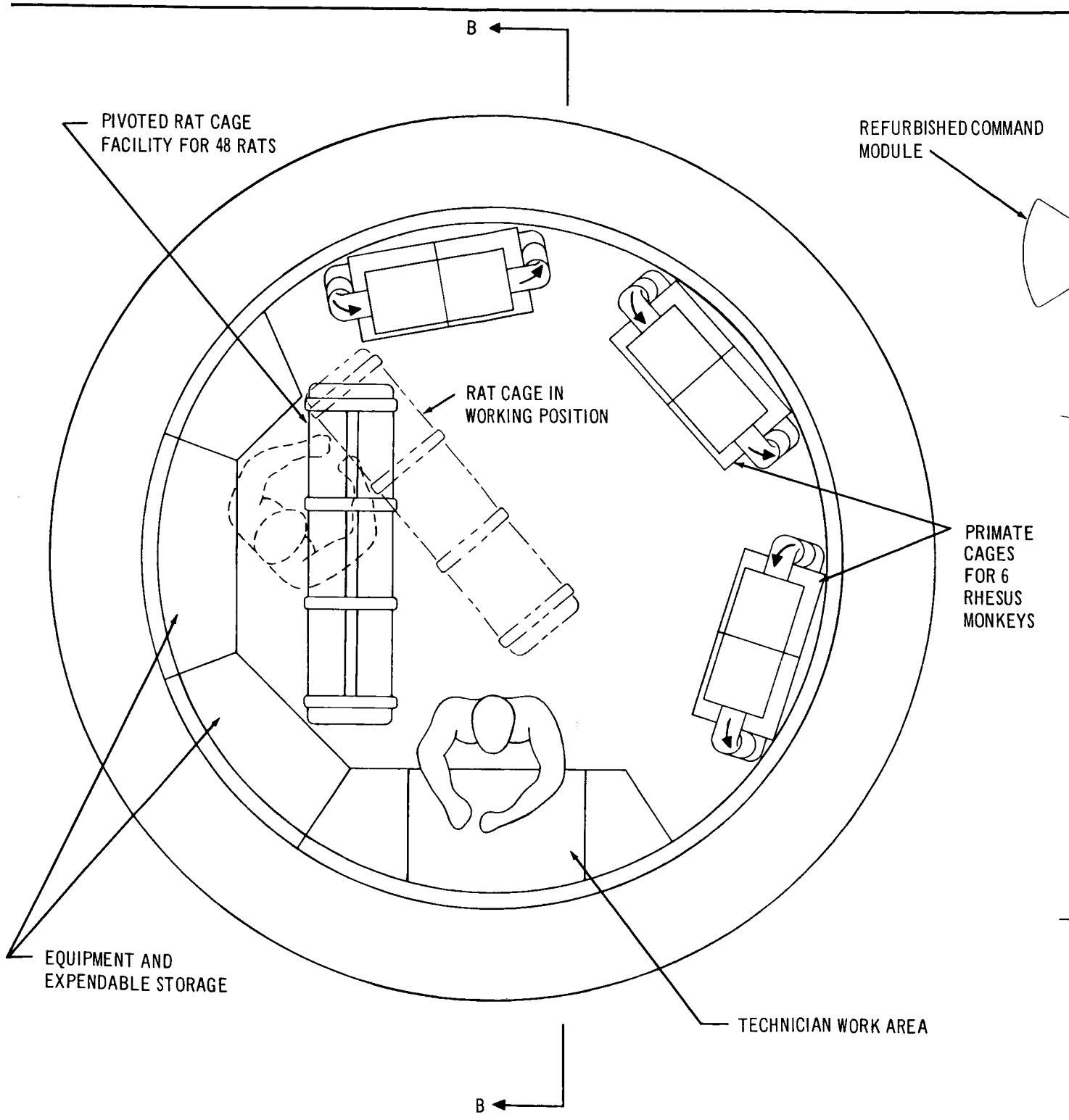

PLAN A-A

FOLDOUT FRAME

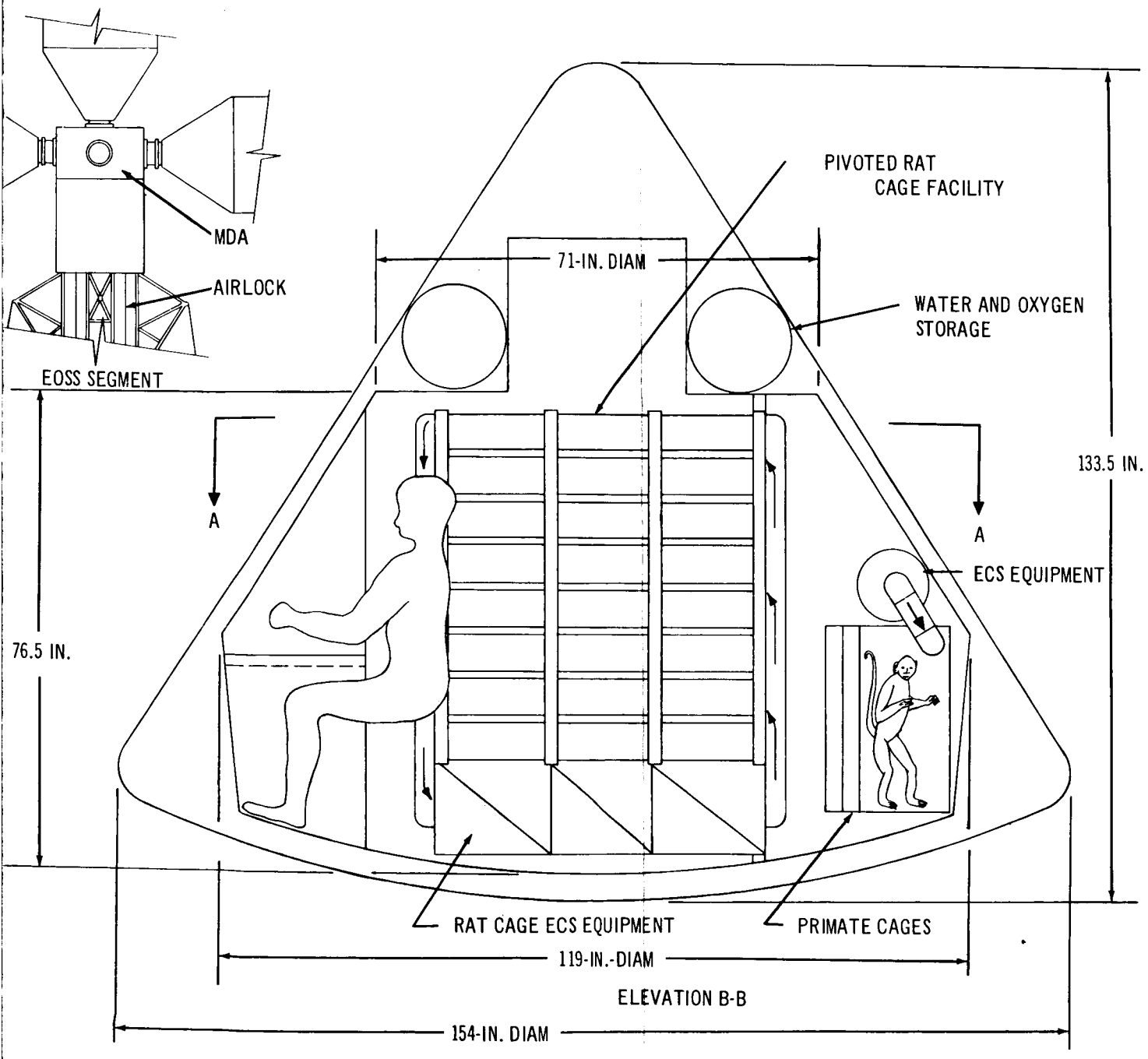

Figure 5-26. Refurbished Command Module Animal Facility Layout (Volume 306 cu ft)

FOLDOUT FRAME

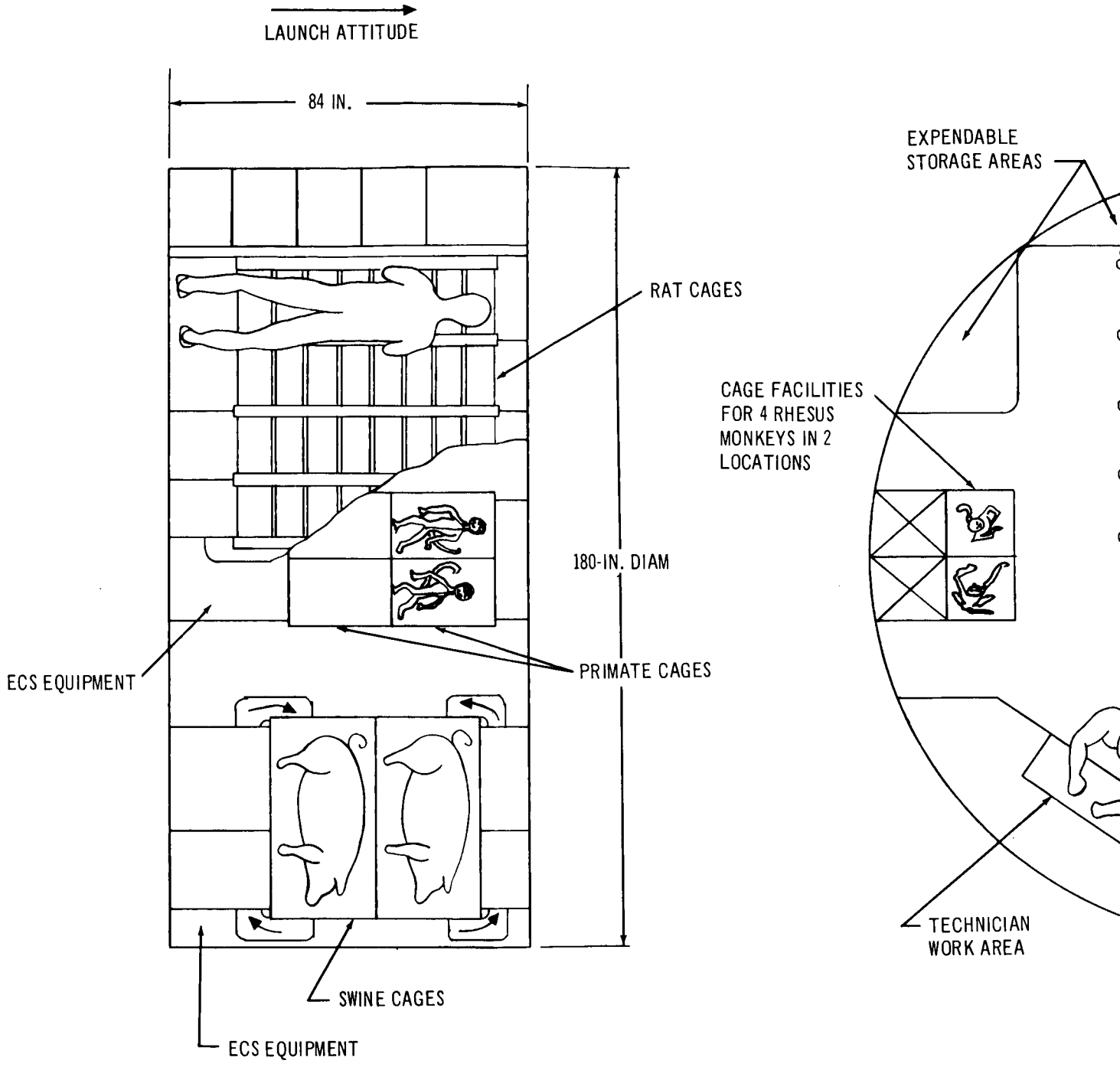

Figure 5-27. Powerhouse Module Animal Facility Layout (Volume 1,230 cu ft)

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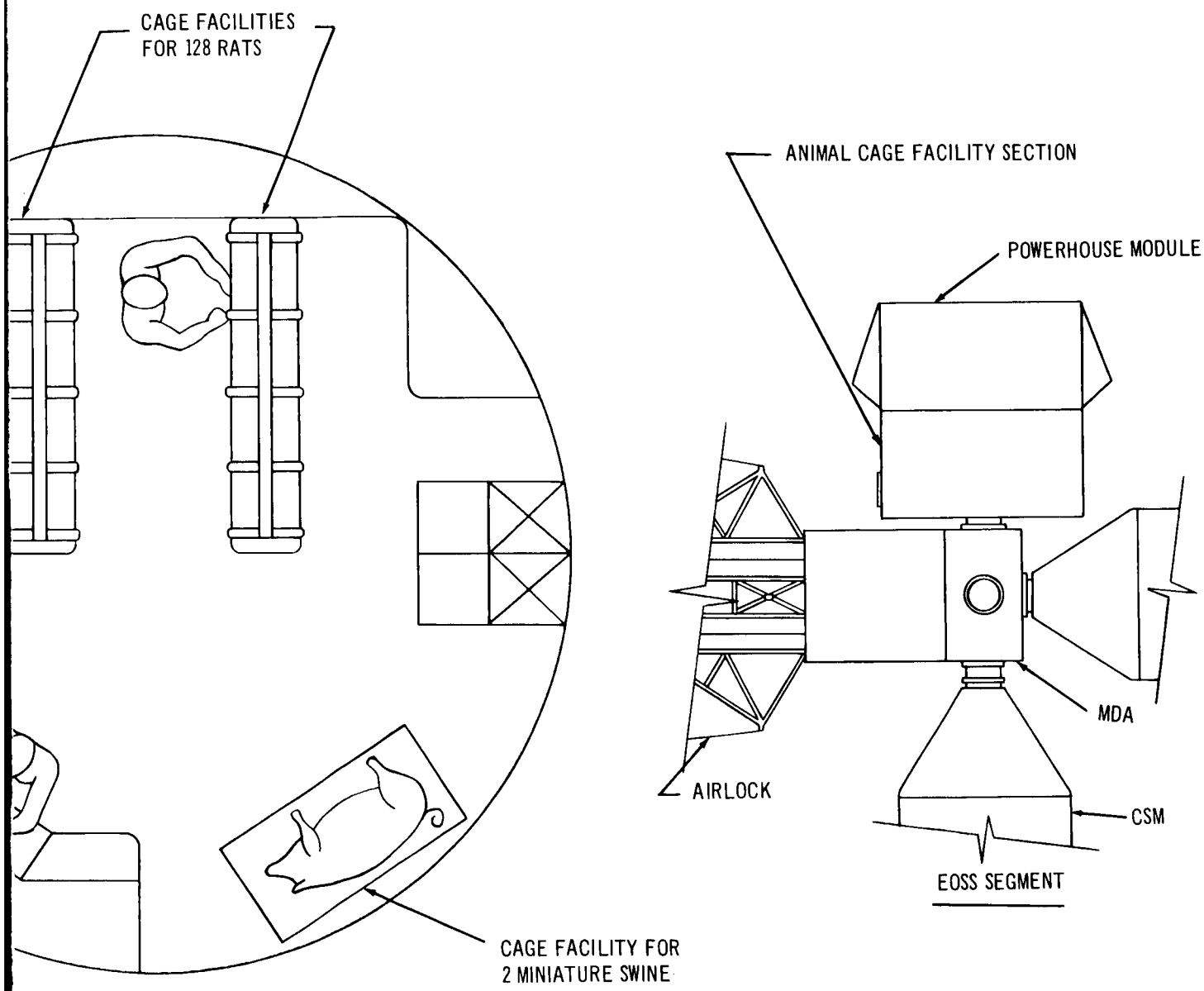

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The nature of the experiment program should be decided by the principal investigator for each separate module concept, and is not discussed in this section. Note, however, that the experiments discussed in Section 2.2 are suitable for sizing hardware systems.

Table 5-5

SEPARATE MODULE ANIMAL FACILITY WEIGHTS* (lb)

	Rats			Rhesus Monkeys		Swine
	48	64	128	6	8	2
Animal Wt	26	35	70	40	53	240
Cage facility weight	97	130	260	75	100	85
Oxygen	80	115	210	100	130	140
Water	100	135	270	115	155	330
Food	65	85	170	47	63	235
Lithium hydroxide	66	88	175	60	75	250
Totals	430	590	1,150	440	575	1,280

*Weights are based on 30 days of facility operation between resupply and exclusive of weight required for electrical power.

Table 5-6

SEPARATE MODULE CONCEPTS
SUMMARY OF FACILITY VOLUMES AND WEIGHTS*

	LEM-Lab	Refurbished Command Module	Power House
Volume, cu ft	250	306	1,230
Facility Weight, lb	590	870	3,000

*Weights are based on 30 days of facility operation between resupply and exclusive of weight required for electrical power.

5.3.1 LEM Lab--Animal-Facility Concept

A layout of an animal facility in the ascent stage of the Lunar Excursion Module (LEM-Lab) is shown in Figure 5-25. The equipment in this layout replaces much of the existing equipment in the LEM. Some thought was given to the amount of control equipment which must remain for docking and telemetry operations with an EOSS. The layout presented may be too ambitious if it is determined that a large amount of the ascent stage equipment cannot be dispensed with. A rat-cage facility only was considered appropriate for LEM-Lab module because of its small size (250 cu ft) and odd shape. By reducing the rat cage size to 5 in. x 6 in. x 9 in., 64 cages were included. The larger circular end of the module would be divided approximately equally into a cage facility and a technician laboratory area (Elevation B-B, Figure 5-25). The ECS for this facility would be a closed-loop system with a heat exchanger for temperature and moisture control as shown on Figure 5-20. The cages would operate at a negative pressure (1 in. H_2O) with respect to "cabin" or LEM-Lab pressure. The facility pressure would be 5 psia as governed by the pressure capacity of the LEM-Lab structure. The cage facility ECS equipment would be located in the pressurized cylindrical container located in the engine bay at the ascent stage. Oxygen and water for this facility would be mounted outside the facility on the LEM "rack" or descent stage structure.

5.3.2 Refurbished Command Module--Animal-Facility Concept

The command module can be utilized to house the animal-research facility shown in Figure 5-26. This layout assumes the removal of all existing CM equipment. The animal population consists of 48 rats and 6 rhesus monkeys. The rat cage structure is two-sided, with 24 cages on each side and with technician accessibility pivoted on one end. The cage units presented here are considered to include integral closed-loop ECS equipment similar to that used in the LEM-Lab. The cages would be held at 1 in. H_2O negative pressure with respect to the CM 5-psi ECS pressure. The rat cage unit ECS equipment is located under the cage bay (Elevation B-B, Figure 5-26), while the monkey cage equipment is located above the cages. Water and oxygen for the facility could be located outside the pressurized vessel around the

docking collar. Food, lithium hydroxide, and laboratory experiment equipment are located in a technician work area as shown in Plan A-A, Figure 5-26. Weight of the facility shown is estimated at 870 lb, (Table 5-6). Pressurized volume is about 306 cu ft.

5.3.3 Powerhouse Module-Animal Facility Concept

A powerhouse module facility is presented in Figure 5-27. The module is 180 in. in diameter, has a depth of 84 in., and a volume of 1,230 cu ft. An animal population of 128 rats, 8 rhesus monkeys, and 2 miniature swine is considered appropriate for a module of this size. Cage sizes for rats are 5 in. x 7 in. x 15 in.; for monkeys 15 in. x 15 in. x 24 in.; and for swine, 24 in. x 24 in. x 48 in. The cage system pressure would be slightly less than that of the module (1 in. H_2O).

The module animal facility would include a separate, closed-looped cage ECS, expendable storage for 30 days of operation, and a technician work area. Facility weights are detailed in Table 5-5. The powerhouse facility weight is estimated at 3,000 lb (Table 5-6).

5.4 SAMPLE RETURN SYSTEM

Two methods of returning biological specimens and material are considered for a workshop or EOSS facility. The first method employs the command module "rock box". This box has a total volume of 1.19 cu ft. In most cases, the biological return material will be frozen, requiring an insulated container with a 1 in. layer of insulation. The net volume of this container would be approximately 0.9 cu ft. This volume would accommodate approximately 50 lb of frozen material.

A second method would employ a "data return" capsule such as proposed by Republic Aviation Corp. for the Advanced Orbital Solar Observatory Program. This capsule could be mounted as shown in Figure 5-10, in the forward skirt area of the S-IVB workshop and return an experiment weight of 10 lb in a container volume of 1 cu ft.

In operation, the capsule would be transported from its launch position in the forward skirt to the laboratory facility through the airlock and opened and loaded with biological sample material. It would then be returned to the forward skirt, mounted for deorbiting and ejected from the space station. The mounting installation for this capsule would include a removable forward-skirt ejection hatch, a capsule guide track, and a pneumatic launch actuator. The capsule once ejected, would be ground-controlled during its return flight.

Section 6
SUPPORTING RESEARCH AND TECHNOLOGY REQUIREMENTS

Supporting research and technology (SRT) items are those items which will require research and development before the operational support requirements of the manned, orbital, animal-research facility can be met. Because of the varied and specialized nature of these SRT items, it is expected that their R&D programs would be conducted in parallel with, but separate from, the basic facility development program.

Many of the SRT items are associated with measurement equipment which currently is gravity-dependent for its operation. Others are associated with laboratory techniques suitable for a manned, zero-g laboratory. This section describes design concepts for selected items. To illustrate a typical SRT program, an experiment that is recommended for the earliest, available, S-IVB workshop mission is described in Section 7 of this report. This experiment would test a design of animal-housing and -handling equipment which will be required in an operational animal research facility.

The design verification of most of the SRT items will only be achieved in a manned, zero-g environment. Therefore, their development programs should begin as soon as possible to take advantage of the NASA space missions planned for this purpose.

6.1 FACILITY SRT REQUIREMENTS

Several of the hardware items constituting the facility which supports the animal colony will require development. A brief description of the requirements for these items is presented in this section.

6.1.1 Animal Housing

Although the prime requirement in the design of the basic animal-housing unit is the well-being of the animal subject, the isolation of the animal-colony

atmosphere from the laboratory atmosphere is equally important. The design must include facilities for manual access to the cage for the removal or insertion of animals or material, with minimum danger of contaminating the laboratory atmosphere. Collars around access parts for the attachment of plastic bags with draw-strings, is suggested. The design of the animal-housing unit is closely associated with waste-management problems (Section 6. 1. 3). The manner in which the atmosphere is distributed to the units requires investigation. Mobility aids for the animals may be required by some experimenters.

6. 1. 2 Animal Feeding Systems

The manner in which food and water are delivered to the animals will depend on the animal and on the investigator. Common reservoirs of paste-type food or water must be protected against retrograde contamination from diseased animals. Dry foods present potential waste management problems in that particulate debris may clog the filters. When the experiment requires that the amounts of food or water consumed must be accurately known, food delivery must be programmed.

6. 1. 3 Animal Waste Management

With smaller rodents, air movement is suggested as a practical approach to the removal of urine and feces from the cage area. However, the use of this method for larger animals such as primates, dogs, or miniature swine will require investigation. Devices which restrain these animals to a waste receptacle on long missions may not be acceptable to the experimenter. Disposal of feces from a colony which includes larger animals may require the use of specially designed containers in which consumables were supplied.

6. 1. 4 Animal Exercise Devices

The design of these devices will depend upon the experimenters' requirements. The suitability of common approaches such as treadmills and ergometers should be explored. The major problem appears to be the provision of a suitable constraint which will permit the animal to exercise, but will not require the attention of the crew. Design concepts of these devices are presented in this report (Sections 6. 5. 2 and 7. 3. 13)

6.1.5 Small-Equipment-Handling Techniques

Problems in this area are not peculiar to a biology laboratory in the zero-g environment, but must be investigated for the handling of devices such as syringes, scalpels, and forceps.

6.1.6 Crew Restraints and Aids

This problem, like the previous one, is not peculiar to the biology facility. The laboratory must provide means for the crew member to perform examinations or surgery in a comfortable position. Mobility aids which permit the crew to transfer restrained animals about the laboratory are required.

6.2 SCIENTIFIC EQUIPMENT SRT REQUIREMENTS

The items discussed in this paragraph are mainly those associated with making measurements or observations. Other items of general laboratory equipment requiring development are included.

6.2.1 Mass-Determination Devices

Accurate mass-determination devices will be required to perform gross pathological and histopathological examinations. Body-mass determination also would be important in fluid balance studies. The masses to be measured range from the rodents' glandular weights to the swines' body weights. It may be necessary to provide more than one device to obtain the required accuracy (for example, a micro mass-determination device with a range of 0.1 g to 4 kg and a macro device with a range of 2 kg to 90 kg). The Langley Research Center sponsored study of a centrifuge for astronauts is expected to yield useful information in this area.

6.2.2 Fluid-Handling and Transfer

The example animal research experiment programs identify several items of equipment which require the development of fluid-handling and -transfer techniques in the zero-g environment. These items include the gas chromatograph, colorimeter, slide and tissue-staining kit, automatic cell counter, automatic plate scan counter, hemocytometer, heomglobinometer, hemostasis kit, film-developing kit, and general fluid-handling equipment. Some of the equipment must handle specimens of urine, blood, and other body fluids, while other

items of equipment are required to perform handling and transfer of chemicals, stains, and so forth. The hazards of contamination resulting from loss of control of such fluids must be considered in approaches to the problem.

6.2.3 Scientific Equipment Required for Animal Measurements

To accurately determine the physiological condition of the animal research subjects, several items of measurement equipment must be developed. These items not only must be capable of operation in a zero-g environment, but also must be adjustable to operate on a variety of subjects. The specific items of measurement and sensing equipment required in the example animal research experiment programs are as follows: (1) sphygmomanometer, (2) electrocardiograph, (3) ballistocardiograph, (4) impedance pneumograph, (5) respiration flowmeter, (6) electromyograph, and (7) electroencephalograph. A variety of animal restraints for use during the actual measurements is also required.

6.2.4 Centrifuges and Associated Equipment

Two types of centrifuges are required to perform the representative experiment programs: (1) an animal centrifuge, and (2) a refrigerated centrifuge. The animal centrifuge is used for exposing subjects to partial-gravity environments for varying lengths of time. This centrifuge must be capable of accommodating a variety of animal subjects. Because of the large size and weight range of the different animal subjects, it probably will be necessary to provide at least two different sizes. An animal centrifuge should contain its own EC/LS and waste-management provisions. The centrifuge study referred to in Section 6.2.1 will also provide useful design data in this area.

The refrigerated centrifuge is used for processing laboratory specimens of urine, blood, and other body fluids. Centrifuge tubes and hematocrit tubes should be provided with valves to prevent fluids from recombining when the centrifuge is stopped.

6.2.5 Treatment Kits

To perform medical/therapeutic experiments on animals in a zero-g environment, treatment kits must be provided for each injury and disease to be studied. The treatment kits should not only provide the medical equipment required to perform therapy, but also should provide a means for inflicting

the injury or disease. Treatment kits should be provided to perform the following medical/therapeutic experiments: (1) fracture, (2) traumatic shock, (3) burn, (4) cut, (5) contusion, (6) radiation, (7) pulmonary irritation, and (8) infection. This kit must be flexible in design to enable it to be adapter to a variety of animal types.

6.2.6 Microscopic Equipment

The following items of microscopic equipment are presently gravity-dependent and will require development to operate in a zero-g environment: (1) automatic cell counter, (2) blood-cell counter, (3) plate scan counter, and (4) hemocytometer.

6.2.7 Surgical Equipment

Many items of surgical equipment required to perform a histopathological examination are presently gravity-dependent. Such items require development or modification so that they can be operated in a zero-g environment. Surgical equipment items which fall in this category include hemostats, microtomes, and tissue-handling equipment.

6.2.8 Specimen-Preservation and -Storage

Because many animal subjects in the example experiment programs are sacrificed at various stages of physiological deconditioning for later pathological examination in a laboratory on Earth, a means of quick-freezing and storing them is required.

The success of the micropathology is dependent upon the rate of freezing, the length of storage before analysis, and the effect of enzyme action. Immersion in a cryogenic fluid with the use of dimethylsulfoxide (DMSO) is suggested; however, handling such fluids in a zero-g environment presents problems. Means of storing the frozen specimen is not in itself a problem. However, it may prove convenient to return the specimens to Earth in the refrigerated storage container. A device of this type will require development. Design concepts for these devices are described in Sections 6.5.4 and 6.5.5.

6.2.9 Impact Sled

An impact sled is required to produce traumatic shock in rodents. Such a device must be capable of operation in zero-g, and will require development.

6.2.10 Bone-Demineralization-Measurement Device

The current method of determining the extent of bone demineralization (that is, by X-rays) will not provide the accuracy of measurement deemed necessary for in-depth studies of the effects of prolonged exposure to a zero-g environment. Another possible method for determining bone demineralization is the use of strontium-85, calcium-45, or barium-140. The need for the development of a more accurate method to be used externally on animals is indicated. This device should be suitable for use both on Earth and in an orbiting laboratory.

6.2.11 Multiple-Parameter Implant Telemeters

The need to monitor the heart rate, respiratory rate, and body temperature of the animal subjects has been described in the experiment program. The technique of monitoring a single parameter with an implant telemeter is well-known. Recent discussions with personnel in the instrumentation development sections at Ames Research Center reveal that they are in the early testing phases of multiparameter implant telemeters. This item is identified here emphasize the need for such a development program.

6.2.12 Radioautography Equipment

The utilization of radioautography equipment requires special handling techniques for tracer materials. Although radioactive materials with a short half-life would utilized, safety precautions would need to be developed to protect the experimenter. Also, to accurately perform experiments, small amounts of fluid would be handled; this handling would require the development of techniques suitable for use in zero-g.

6.3 EXPERIMENT SUBJECT SRT

6.3.1 Animal-Subject Training and Development

Although this SRT item does not call for the advancement of the state of the art, it will be necessary to train the animal subjects to perform certain tasks essential to the experiment program. The ability of the animals to absorb this training must be proven before the mission is undertaken. This training will include such tasks as consuming food and water in the manner provided by the zero-g devices; performing on the exercise device; and, for the best operation of the proposed waste-management system, to defecate and urinate only when facing into a flow of air.

It is appreciated that many of the researchers considering animal experiments in space would prefer that a 14.7-psi "Earth atmosphere" be used throughout the entire program. This philosophy is supported by biology specialists at Douglas. However, the S-IVB workshop as presently planned specifies a 5.0-psi (3.5 O_2 and 1.5 N_2) atmosphere. Numerous design and handling problems are associated with operating an animal colony at a positive pressure differential to the manned space laboratory. If these problems preclude the use of a 14.7-psi atmosphere for the animal colony, Douglas suggests that terrestrial colonies of each type of the selected animals be established as soon as possible at a 5.0-psi two-gas system, or whatever atmosphere is compatible with the final workshop design. Such colonies should be maintained for a period long enough to be able to attain sufficient baseline data and proper experimental and control animals for the proposed mission.

6.3.2 Animal-Subject Handling Techniques

The success of the mission will depend, in part, upon the suitability of the handling techniques used by the crew. An SRT item is identified as "animal-handling techniques." Safety for the experimenter is of paramount importance, because of the limitations for treatment in a space environment. An earlier flight utilizing a selection of techniques would serve to illustrate inadequacies before the full mission is undertaken.

6.3.3 Animal Subjects EC/LS Requirements

The data in Section 2.3.4 were presented for sizing EC/LS systems only, and should not be treated as accurate, experimental, biological data. Therefore, precise EC/LS requirements for all subjects must be determined. These requirements (for example, food intake, water intake, oxygen intake, carbon dioxide output, and heat output) should be determined using the environmental conditions (except for zero-g) and diet to be used in the orbiting animal research facility.

6.4 SRT EFFORT SCHEDULE REQUIREMENTS

The relationship of the SRT program schedule to the facility and space-station development programs is discussed in Section 8.4 of this report. For the majority of the SRT items identified, a development program of 18 to 24 months is anticipated before flight-qualified hardware would be available. This development time, coupled with the need to deliver the flight hardware to the space-station integration facility 6 months to 1 year before launch, creates a critical problem if a biology program is to be prepared for the first, long-duration space station (EOSS) in the 1971 through 1972 period. The need for an immediate start of SRT programs is clear if use is to be made of S-IVB workshop missions in the 1969 through 1970 period.

6.5 SELECTED SRT ITEM DESIGN CONCEPTS

In preceding portions of Section 6, only the problems associated with the SRT items were outlined. In this section, design concepts for five of these items are described. They are presented to illustrate one design approach to assist NASA in evaluating the scope of effort necessary in the development of the item. The design concept described should not be considered as a recommended one. This could only be done after a comparative analysis of several approaches which would properly be accomplished in the individual SRT development programs.

6.5.1 Rodent Exercise Device

A design concept for a rodent treadmill has been prepared. Because it was included in the early experiment program, the full description will be found in

Section 7. 7. 3 of this report. Briefly, the device consists of a treadmill and self-imposed restraint to hold the rodent in a position which will enable him to exercise. An electronic programmer determines the duration of the exercise, and the level of strenuousness may be adjusted at the treadmill. Use of the exerciser is part of the animal's feeding program. A successful animal training program will be necessary to make the system effective.

6. 5. 2 Primate Exercise Device

Exercise can be accomplished in a zero-g environment, if suitable restraints and exercise devices are provided. Figure 6-1 schematically illustrates a primate exercise-device concept based on an arm and leg pedalling system. By "hunching" down, the primate can place himself on a suitable torso- or back-restraint device and turn either or both of two pedal units. The pedal units would be coupled with adjustable brakes and revolution counters. The level and duration of exercise could be set by an operator or be automatically controlled by a programmer. Feeding and exercise could be programmed for any experiment program and be coupled with biomedical parameter-sensing functions as described for the rodent exercise device.

6. 5. 3 EC/LS for Swine

An EC/LS system for swine would, in concept, be the same as that proposed for rats. The concept of using air motion for sweeping waste and debris from the air would still apply. A waste pad downstream of each cage would retain the waste while drying it, and environmental control equipment would purify, cool, and dehumidify the air. The required air velocity to move the waste from the swine should be somewhat higher than for rats because of the larger particles involved. However, the increase can easily be obtained by increasing the ventilation fan power while sizing the swine cages and related EC/LS equipment.

6. 5. 4 Experiment Subject Preservation and Storage Method

Sample preservation and storage will be accomplished by freezing and, where appropriate, by lyophilization. Freezing and lyophilization are the preservation techniques of choice, rather than fixation and formalin preservation

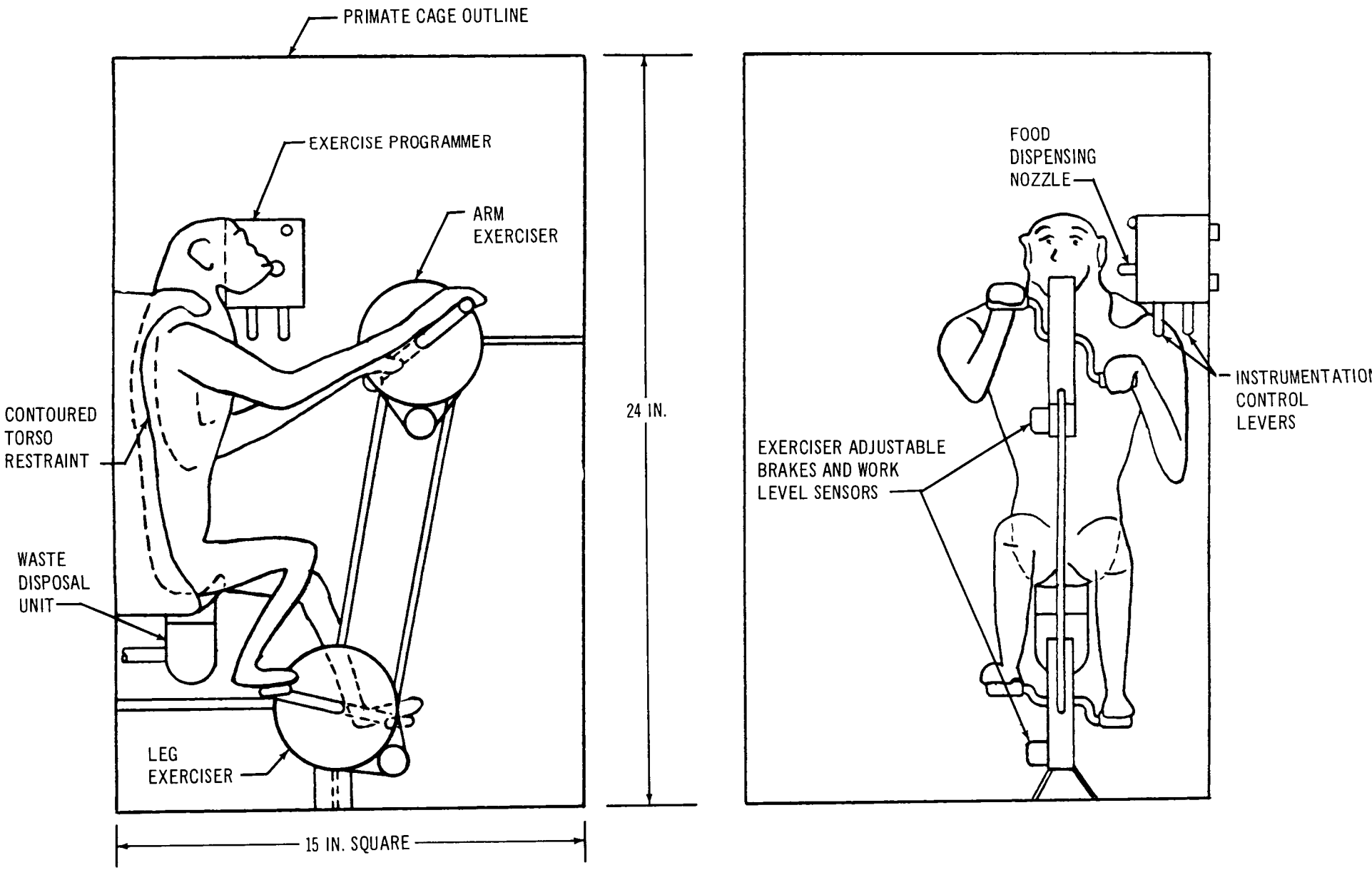


Figure 6-1. Primate Exercise Device

because the use of formalin would cause dangerous outgassing of formaldehyde. Technical considerations were directed toward a method of preservation and storage which would allow for minimum loss of the desired chemical constituents of each specimen, as well as maintenance of the optimum integrity of the cells and tissues. It was determined that blood plasma, urine, and feces specimens could be preserved best by lyophilization. Preservation of plasma, serum, and feces is done presently in terrestrial laboratories. Application of lyophilization to the preservation of urinary solids is a feasible concept, but would require additional research and development. Tissue and whole animal specimens have been preserved by cryogenic means in terrestrial studies, and baseline data is being accumulated. Although most histopathological studies have been done on formalin-preserved tissues, rapid progress is being made in cold temperature techniques. (Most tissue and animal specimens would be perfused with DMSO prior to freezing.) Sufficient baseline data should be accumulated with freezing techniques prior to flight studies. Standarized techniques should be established for each type animal to be used in the laboratory.

Lyophilization is based on the physical fact that the vapor pressure of ice at $0^{\circ}C$ is 4 mm Hg. If aqueous solutions, suspensions, or certain colloids are frozen then exposed to absolute pressure below 4 mm Hg, water will be rapidly removed by sublimation. Specimens must be frozen rapidly to prevent protein denaturation resulting from aggregation of proteins and concentration of salts. Liquid specimens should be frozen rapidly to prevent frothing and loss of volatile substances. Disposable liners and suitable individual specimen "overflow" traps and absolute filters should be used around the specimens to save as many volatile substances as possible to prevent contamination of the apparatus or of succeeding specimens, and to prevent discharge of contaminants to space. Urine, blood, tissue, and intact animal specimens will be collected. Whenever possible, these specimens will be examined presumptively and/or terminally in the space laboratory. However, most specimens will be returned for Earth analysis. Specimens of blood and urine will be collected in vacuum type syringes which have been sterilized and packaged prior to flight with suitable quantities of anticoagulants, precipitants, and so forth. Where appropriate, the vacuum type syringes will also serve as

centrifuge tubes. Douglas has developed a one-way-valve type of tube for zero-g use which keeps different density fluids and cells separated after centrifugation.

The following is a suggested system for lyophilization and freezing which would be appropriate for an animal research laboratory. The size of this unit can be adjusted depending upon the size, number, and type of specimens to be stored aboard the space vehicle, and whether these specimens were to be examined in flight or returned to Earth and examined. This preservation storage apparatus is identified as an SRT item and is shown in Figure 6-2.

Cryogenic fluid (nitrogen) will be placed in the unit prior to launch. At a suitable period prior to launch, the liquid nitrogen will be subjected to a high vacuum and will be solidified. During flight and during use in the workshop, boiloff of gaseous nitrogen will be controlled by suitable vapor pressure relief valves vented to space. With proper control of relief valves, boiloff of nitrogen can be suitably regulated to provide any temperature desired.

The boiloff N_2 passes through cooling coils surrounding the refrigeration freezer storage or lyophilization unit, returns to pass around the solid N_2 and around the periphery of the freezer-storage-lyophyilization unit, then vents to space.

Lyophilization involves quick cryogenic freezing of the specimen and continued lowering of the temperature to the desired temperature range. To ensure that a specimen undergoing sublimation remains substantially free from traces of liquid, the process is always carried out with the unsublimed protion of the specimen at a temperature below the freezing point of water. (The optimum values are -20° to -60°C.) When the specimen sublimes, it absorbs the latent heat of sublimation which is equal to the heat required to melt it and then to change the liquid into a vapor. If external heat is not supplied to cause the change of state, it will be obtained from the specimen itself. As this occurs, the ice solids tend to crystallize, preventing the molecules from escaping, and thus effectively reducing the sublimation rate. Therefore, for continued sublimation, external heat has to be added to maintain the desired sublimation rate. As noted in Figure 6-2, rf heating is supplied close to specimen, and uniformly heats the specimen throughout, assuring uniform sublimation.

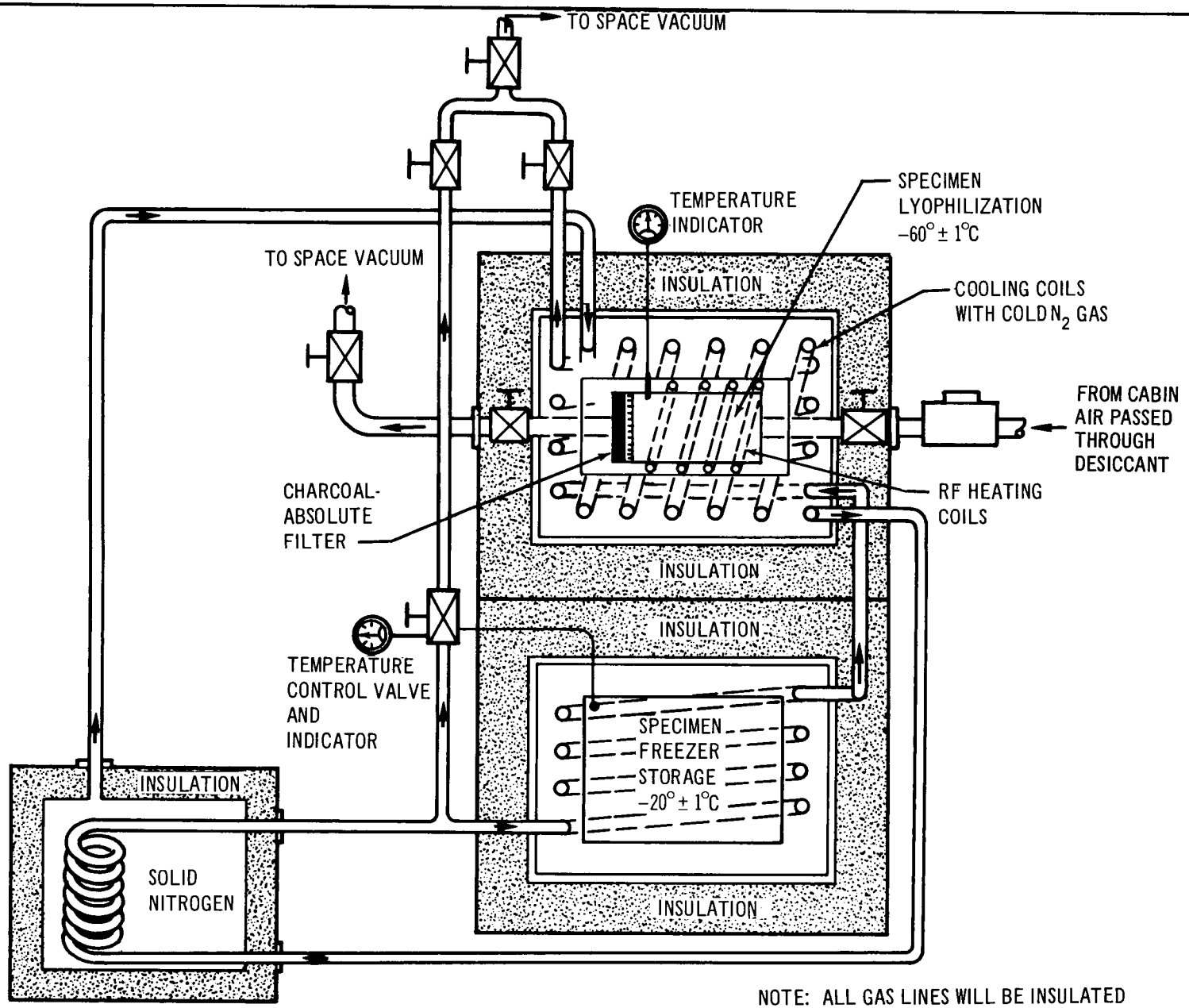


Figure 6-2. Lyophilization-Freezer Storage Unit

Temperature of the specimen freezer unit will be controlled by a temperature sensor valve which will shunt part or all of the nitrogen boiloff through its cooling coils. After the valves have been set, the lyophilization unit is self-regulating.

Depending on the type of sample and the aims of the experimenter, specimens will either be lyophylized and then placed in the freezing storage unit, or the specimens will be placed directly into the freezing storage unit.

Section 7
EXPERIMENT DESIGN FOR INITIAL SRT EFFORT

One of the tasks in the animal research facility study was a design study of an experiment associated with the SRT items, which could be performed in an early S-IVB workshop mission. After coordination with the Contract Manager at NASA (OART), it was agreed that the development of animal housing and handling techniques for a manned space station should be undertaken as soon as possible. The experiment design study, therefore, addressed itself to this subject. The results of that study are presented in this section.

To verify the suitability and effectiveness of the designs suggested for testing, it is necessary to include a quantity of 250-gram rats in the experiment. The opportunity exists to perform a biology experiment which, by using these animals as subjects, may be conducted together with the equipment experiment. Personnel in the Life Sciences Directorate at the NASA Ames Research Center were contacted to determine whether they could suggest such an experiment that could be conducted in conjunction with their current research programs. Although they recognized the potential value of such circumstances, they indicated that the status or nature of their research programs at this time precluded the definition of an associated zero-g experiment. Therefore, lacking a suggestion from Ames Research Center, Douglas has included in this report a brief description of a candidate experiment. This experiment is not to be construed as a recommendation; for although it is meaningful, it is only representative of many that may be performed. The eventual design of the facility must accommodate and satisfy ARC requirements.

7.1 EXPERIMENT OBJECTIVES

The objective of any experiment proposed for an orbital mission must meet the requirement that the information sought can only be obtained the the space environment and not by simulation techniques on Earth. The objectives of this experiment are discussed in this context in this section. Zero-g is the only characteristic of the space environment with which this experiment is concerned.

7.1.1 Equipment Evaluation

The equipment designs described in Section 7.3.1 were prepared to meet the requirements of an animal research facility in either a spent S-IVB mission or a space-station mission. Several of the functional aspects of these designs must be tested in a zero-g environment before the designs can be accepted for general application.

The rat activity module is proposed for use as a restraint device and couch during the launch phase in either type of mission. Successful testing in a centrifuge on Earth will be verified by actual launch conditions.

The effectiveness of air motion for waste management can only be tested in zero gravity. The design of the waste filters will be evaluated as part of this system.

The multifunction rat activity module design must be evaluated together with the capability of the rat to retain his "1-g" training and successfully operate the equipment in the zero-g conditions.

The "cage" size proposed is less than that recommended for housing rats on Earth. Observations of the behavior of the rat in zero gravity in a cage of this size are required with a view to further reducing the size.

The designs of all of the equipment must be evaluated on the basis of the ease with which the crew can perform the associated tasks. Observations and comments are required on tasks such as facility setup and maintenance and animal handling.

7.1.2 Biological Data

Many types of biology experiments may be conducted using the animals required for the equipment-evaluation experiment. An illustrative example of such an experiment is described in Section 7.4. The objective of this experiment is the acquisition of preliminary data on the effects of exercise on the deconditioning of the cardiocvascular system in the weightless state.

Another objective is observation of the general behavior of the rats in the weightless environment. It has been suggested that they may "gravitate" with

the air flow to the waste filter screen and remain there, secure in feeling of the partial "downward" pressure resulting from the air flow. As mentioned in a previous paragraph, their ability or inability to retain their training in the weightless state will have a dramatic impact on the future design of experiments and equipment.

7.2 EXPERIMENT CONDITIONS

This experiment has been designed to be performed in an spent S-IVB workshop mission of at least 28-day duration.

7.2.1 Prelaunch Phase

During the prelaunch phase, the experiment package will be installed in its launch position in either the MDA or S-IVB forward skirt. This will require the equipment to function normally for approximately 1 day under launch-site conditions. This environment will be in accordance with the applicable portions of the natural terrestrial environmental conditions defined in NASA TM X-53328.

7.2.2 Launch Phase

During the launch phase, the experiment packages (animal-launch capsule, experiment cages, support equipment, and biomedical equipment) will be attached to the vehicle structure. This will subject the experiment to shear, vibration, thermal vacuum, and other launch-induced conditions. Detailed flight loads are defined by Paragraph 3.1.1.1.2.3 of S-IVB CEI Specification CP 208009A. Vibration, shock, and acoustic requirements are contained in Design Memo 110A, MSFC Internal Note 1N-P and VE-S-63-1, dated 14 August 1963.

7.2.3 Passivation and Activation Phase

During these phases, the experiment packages will remain attached to the structure of the vehicle. This will require the animal launch capsule to automatically maintain a habitable environment for (approximately) the 4 days between initial orbit and the time when the experimental equipment is

transferred into the workshop and setup. The passivation and activation phase sequence are defined by NASA Drawing 10M31014, Orbital Workshop Astronaut Review Outline.

7.2.4 Experiment Actuation Phase

After the orbital workshop has been passivated, activated, and habitated, the various experiment packages will be transferred by the astronauts from their launch-storage location through the airlock module (AM), through the upper LH_2 tank hatch, and down to the working area.

If the experiment package is mounted on the outside in the forward skirt area, the astronauts will be required to don their pressure suits, depressurize the AM, open the AM hatch, translate to the position on the aft skirt where the experiments are stowed, release them from stowage, and transfer the package(s) back into the AM. The AM hatch will then be closed and the AM repressurized. The astronaut will then transfer the experiment packages down into the working area and commence experiment "setup". Experiment setup will require the astronaut to activate the permanent "cages"; activate and checkout the ECS, waste, and food management systems; and transfer the animals from the launch vessel into the experiment cages.

Additional cage support, medical support, and biomedical-monitoring equipment will also be removed from storage, set up, and checked out.

7.3 EQUIPMENT EXPERIMENT

The description of the equipment design evaluation experiment has been separated from the biology experiment (Section 7.4) to facilitate planning and to emphasize the illustrative nature of the latter. Designs suggested for testing result from the requirements developed in this study. In keeping with the intent of this contract, complete comparative analyses have not been conducted on the details of equipment. Subsequent effort in an experiment design program may reveal more effective approaches; however, positive results from the testing of the equipment described will constitute a sizable step toward development of an animal research facility.

7.3.1 Equipment Description

The major items of equipment and systems to be evaluated in this experiment are described in this section. Except for the animals permanent cage-unit assembly, all designs have been scaled down to accommodate the number of animals involved. This is acceptable for evaluating the design principles. If a biology experiment of the type described in Section 7.4 is performed, animal preservation and storage devices as described in Sections 6.5.4 and 6.5.5 would also be required.

7.3.1.1 Prototype Animal Launch Capsule

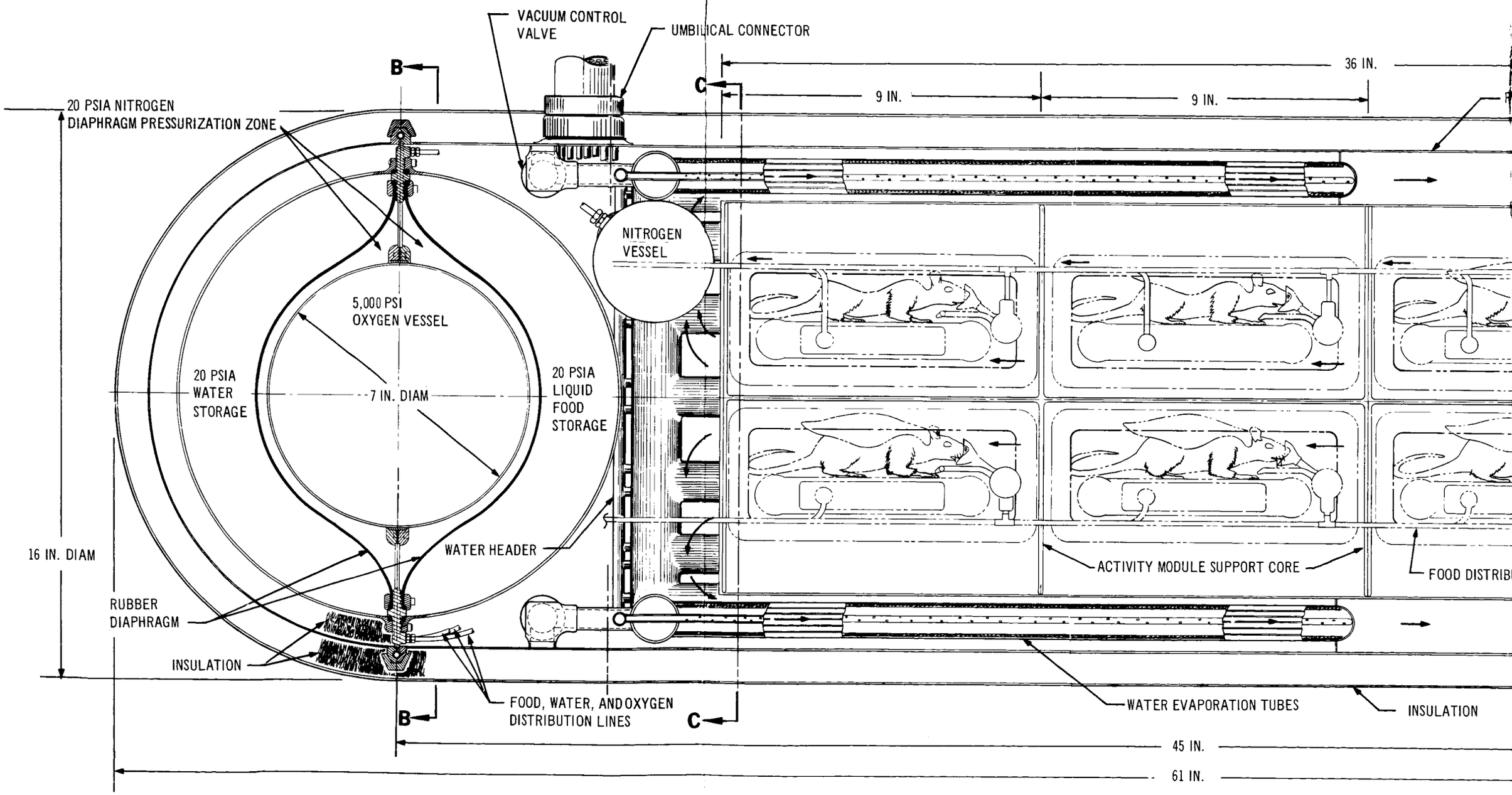
A prototype animal launch capsule concept, sized to transport and support 16 250-gram rats for 6 days prior to their transfer to permanent "cages" is shown on Figure 7-1. This module is 16 in. in diameter, 61 in. long, and weighs approximately 110 lb. The capsule is basically a cylindrical pressure vessel with removable hemispherical ends and has an internal working pressure capacity of 15 psi. The capsule is completely insulated and has an active EC/LS system. The rats are housed in rat activity modules which also serve as a launch and transfer modules. These modules, together with the launch capsule, provide all life-support requirements, including feeding and exercise, and are remotely controlled and monitored. Two instrumentation connections are required to the module for prelaunch and post-launch operations.

Functional Requirement

The launch capsule presented functions primarily as a life support and transport capsule for the animals. It is intended to operate 3 days before and 3 days after launch until the animals can be transferred to a permanent workshop laboratory facility. Functional requirements include physical support for the animals during launch, EC/LS systems, provisions for exercise, food distribution, instrumentation, waste management, and critical biological parameter monitoring.

EC/LS Description

The capsule has a complete EC/LS system which includes provisions for temperature control, relative humidity, carbon dioxide, and waste-material



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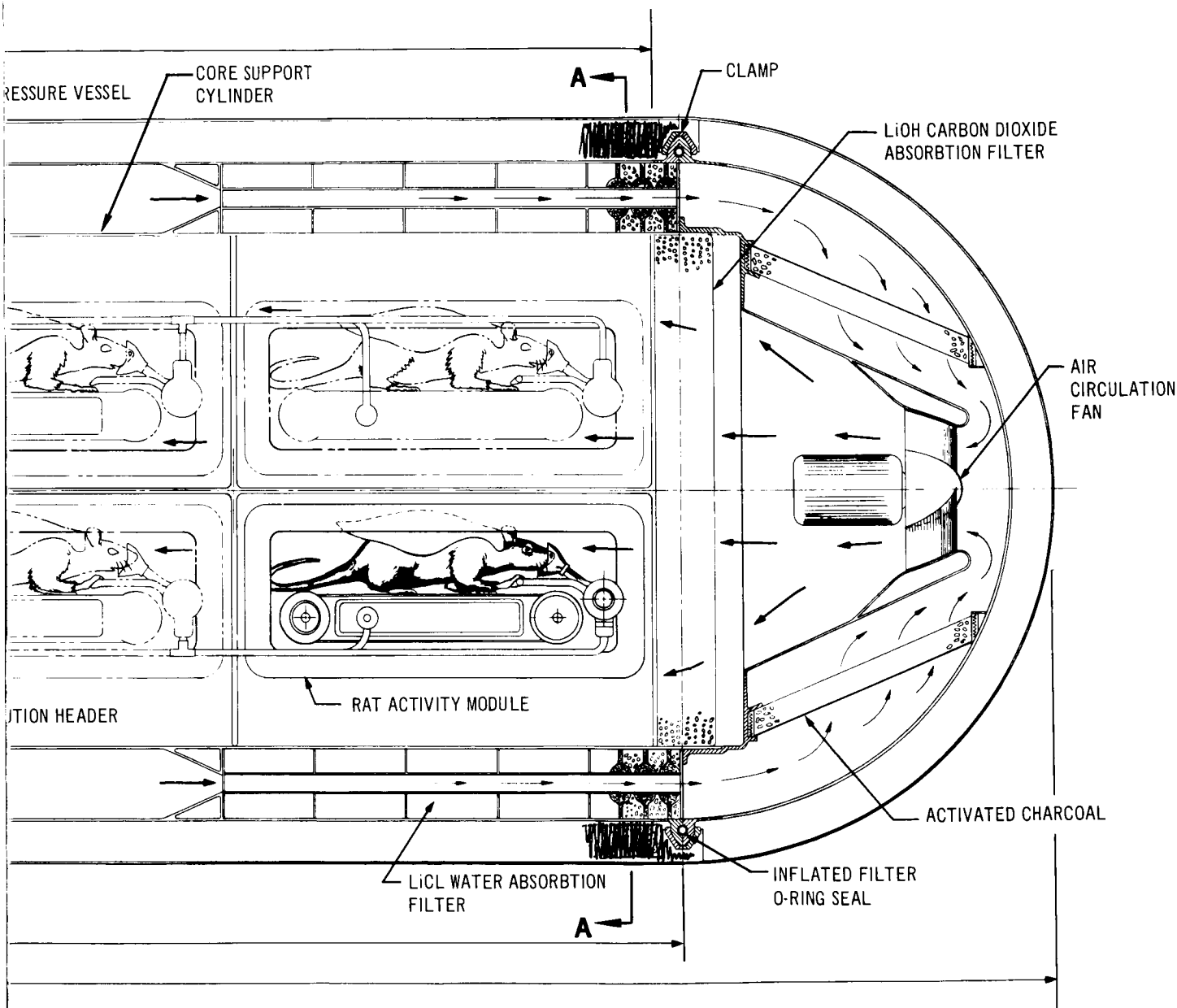

Figure 7-1. Elevation-Prototype Animal Launch Capsule

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152C

control. The module, insulated by polyurethane foam or similar insulating material, would be cooled by a vacuum water evaporating system. This system can be seen in Figure 7-1 and in Section C-C of Figure 7-2. It consists of a toroidal vacuum tube header and finned tubes located between the outer pressure shell and the inner core cylinder. Air returns from the cage area of the capsule core through the finned tube area, where it is cooled. Water evaporating from wicking material inside the vacuum tubes effects the cooling. Water from a diaphragm pressure reservoir is distributed to the vacuum tubes through perforated water-distribution headers as seen in Figure 7-1. The cooling capacity of this system is governed both by the control of water distributed to the vacuum evaporation tubes and the control of the vacuum level in the evaporation system. This system would hold the capsule temperature at $70^{\circ} \pm 5^{\circ}$F.

The relative humidity of the capsule would be controlled at 50% ±5% by removing water from the air, after it is cooled, by a lithium chloride filter section located near the fan end of the module (Figure 7-1). The lithium chloride is laminated with layers of sponge material which provide for its expansion when absorbing water. Contaminants are removed from the capsule air before entering the fan by an activated charcoal filter. Carbon dioxide is removed from the air by a lithium hydroxide filter before air entrance into the cage section. Table 7-1 summarizes the quantities of the materials required by the ECS.

The atmosphere for the capsule concept presented here is a combination of oxygen at 3.5-psi partial pressure and nitrogen at 1.5-psi partial pressure, with a total pressure of 5 psi. Oxygen and nitrogen are stored in spheres at the left end of the capsule as seen in Figure 7-1. The oxygen required before launch is supplied through the umbilical connector. Air is circulated through the cages in series fashion by a single 10-W fan. At the downstream end of each cage is located a waste filter which collects fecal matter and urine. The filter is designed to allow this material to dry and also to prevent the passage of any harmful material to downstream animals.

Expendable Storage

At the left end of the launch capsule (Figure 7-1) the EC/LS systems storage area is located. Water is stored here in a spherical container for the

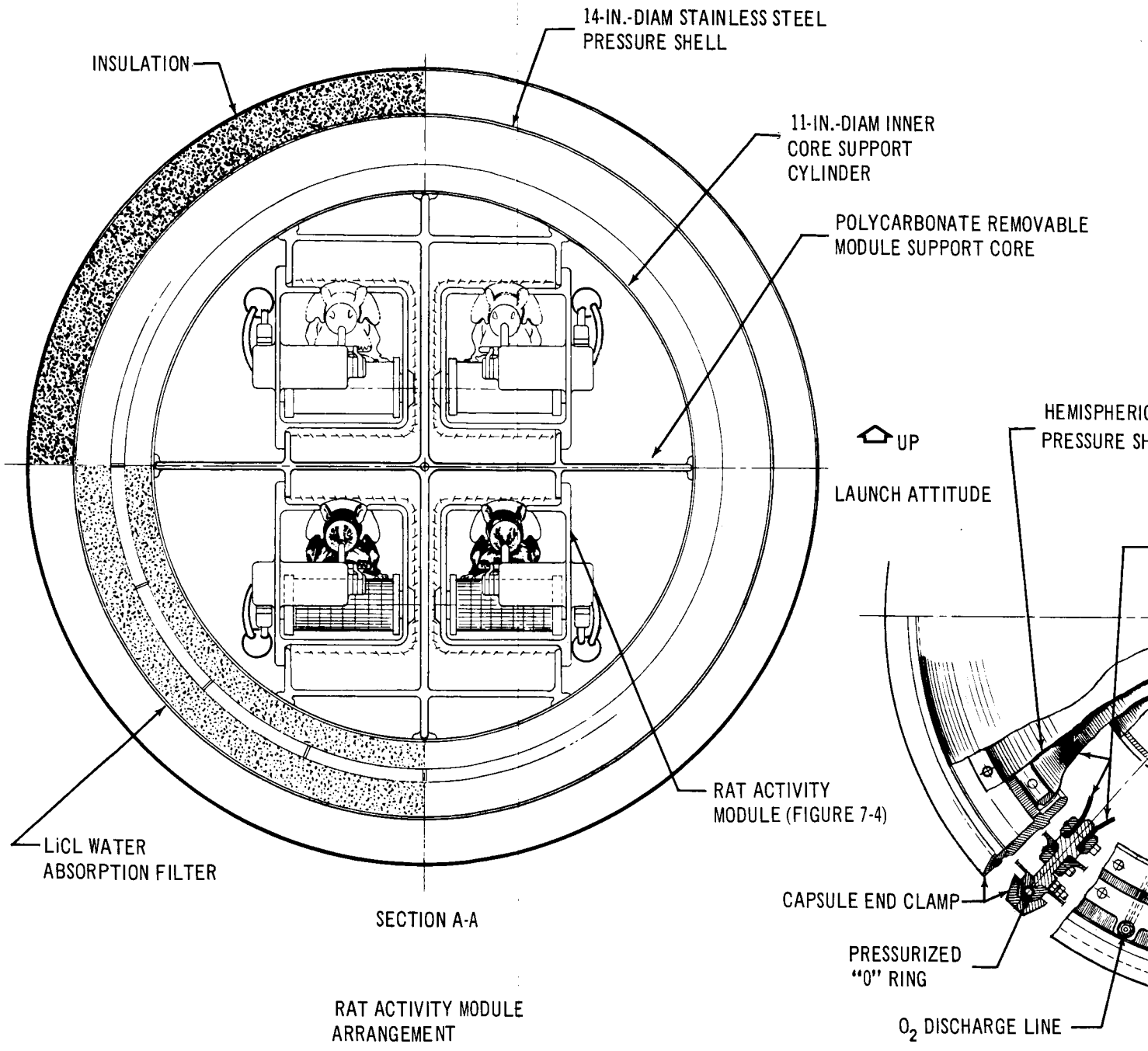

Figure 7-2. Sections – Prototype Animal Launch Capsule

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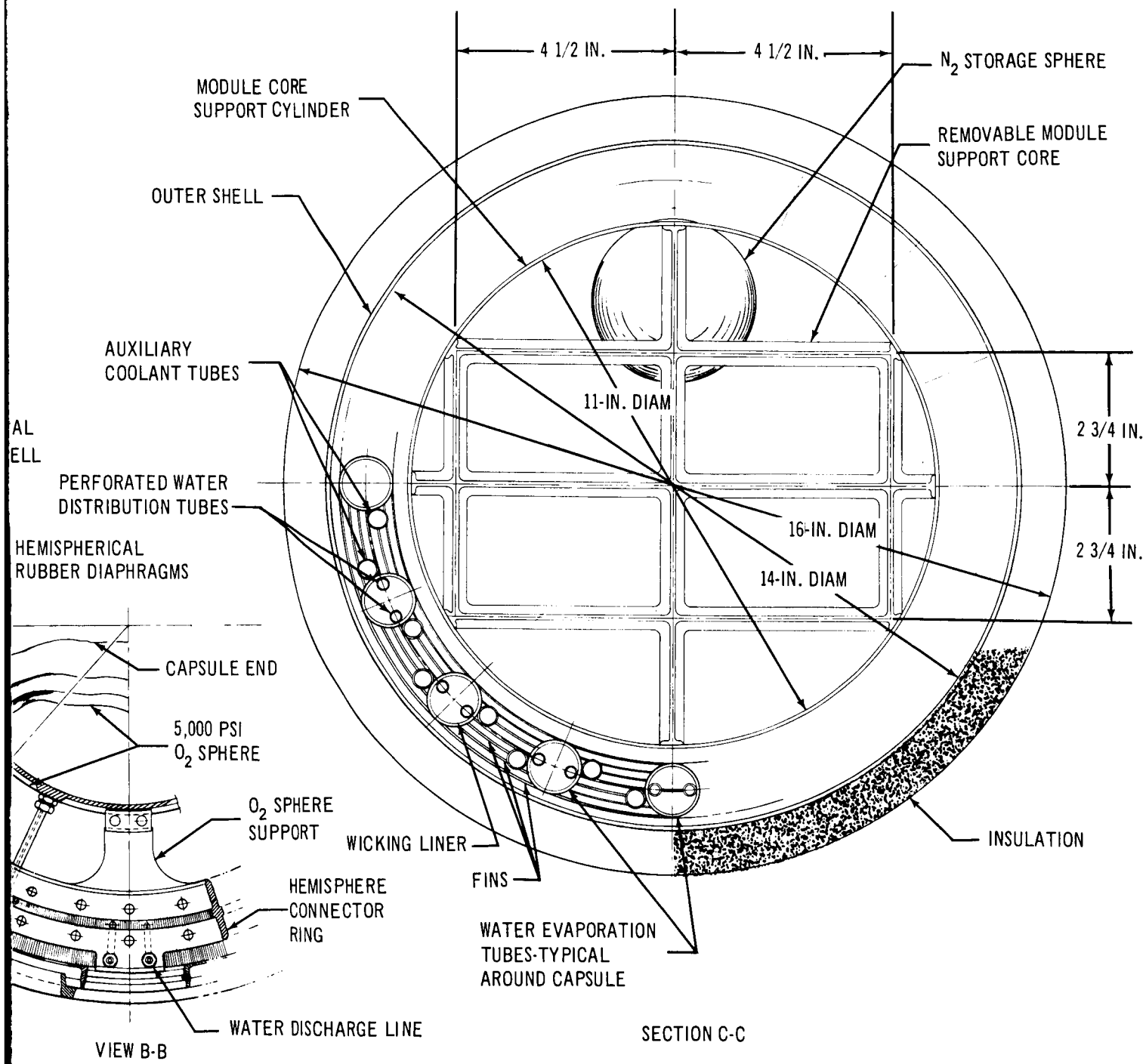

XPENDABLE STORAGE SPHERE

CAPSULE COOLING SYSTEM

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Table 7-1

PROTOTYPE ANIMAL LAUNCH CAPSULE
MATERIAL WEIGHT SUMMARY

Material	Volume (cu in.)	Weight (lb)	System Capacity (days)
LiOH	371	5.4	6
LiCl	373	7	6
Water	390	14	3
Oxygen	177	24	3
Nitrogen	14	0.1	6
Activated charcoal	100	0.6	6
Food	315	11	6

water-evaporation cooling system, oxygen, and liquid food. The oxygen is stored in a 5,000-psi, 7-in. diam vessel in the center of this spherical storage container. Surrounding the oxygen pressure sphere are two pressurized diaphragms. These two diaphragms and the outer hemispherical shells surrounding them provide the storage volume for the water and liquid, gelatinous-type food. The oxygen, water, and liquid food are all manifolded out of the storage container through an annular support ring as seen in Section B-B, Figure 7-2. This annular ring provides the separation between the water and the liquid-food storage areas and provides the manifold paths through which the materials are distributed to the capsule. The storage sphere would contain enough water and liquid food for a maximum of 6-day capsule operation.

Capsule Operation During Launch

During a mission, a launch capsule is located initially in the forward skirt of the S-IVB with its centerline axis oriented horizontally and with the animal activity modules oriented as shown in Section A-A, Figure 7-2. In this orientation, the rats are supported by either the exercise device belt or an equivalent pad during launch. Before launch, the capsule is connected through an umbilical to the launch stand. The umbilical connection supplies an auxiliary coolant to the capsule while it is on the launch pad, provides oxygen and electrical power from external sources, and provides instrumentation

circuits for monitoring critical, animal, biological, functional parameters during the period before launch. Removal of the umbilical connection at launch activates the capsules water-evaporation coolant system, cuts off the external oxygen and power-supply circuits, and diverts the animal parameter-monitoring activity to vehicle-oriented telemetry systems. An instrumentation coupling, besides the umbilical coupling, is required for this purpose.

Capsule Transport and Disassembly

After stage passiviation and facility activation, the animal launch capsule is removed from the forward skirt and transported into the S-IVB workshop via the AM. Capsule monitoring is suspended because of the removal of the instrumentation connection to the capsule during the capsule-transfer operation. Once inside the workshop, the instrumentation connection to the capsule is recoupled and capsule disassembly commences. Capsule disassembly is accomplished by removal of two clamping bands at the ends of the capsule and removal of the hemispherical capsule ends. Removal of the left end of the capsule (Figure 7-1), including the spherical storage vessel, allows disconnection of the instrumentation and food distribution duct headers from the animal activity modules in the capsule core. The capsule core can then be removed from the capsule by sliding it out of the inner capsule liner to the right (Figure 7-1). After core removal, the rat activity modules can be disconnected from tube and instrumentation harnesses, removed from the core, and transferred to permanent cage facilities in the workshop. Installation of the modules in the permanent cage facility would be completed by the recoupling of food distribution and instrumentation connections.

7.3.1.2 Prototype Animal Housing and EC/LS

A prototype animal housing and EC/LS facility for a colony of 16 rats is shown on Figure 7-3. This facility is designed to test the merits of the similar full-scale facility described in Section 5.1.2. The prototype facility cages, ECS equipment, instrumentation, and tehcnician restraint system would be essentially the same as required for a full-scale facility. The subsystem requirements and design concepts for such a facility would be based on those described in Section 5.1.1.

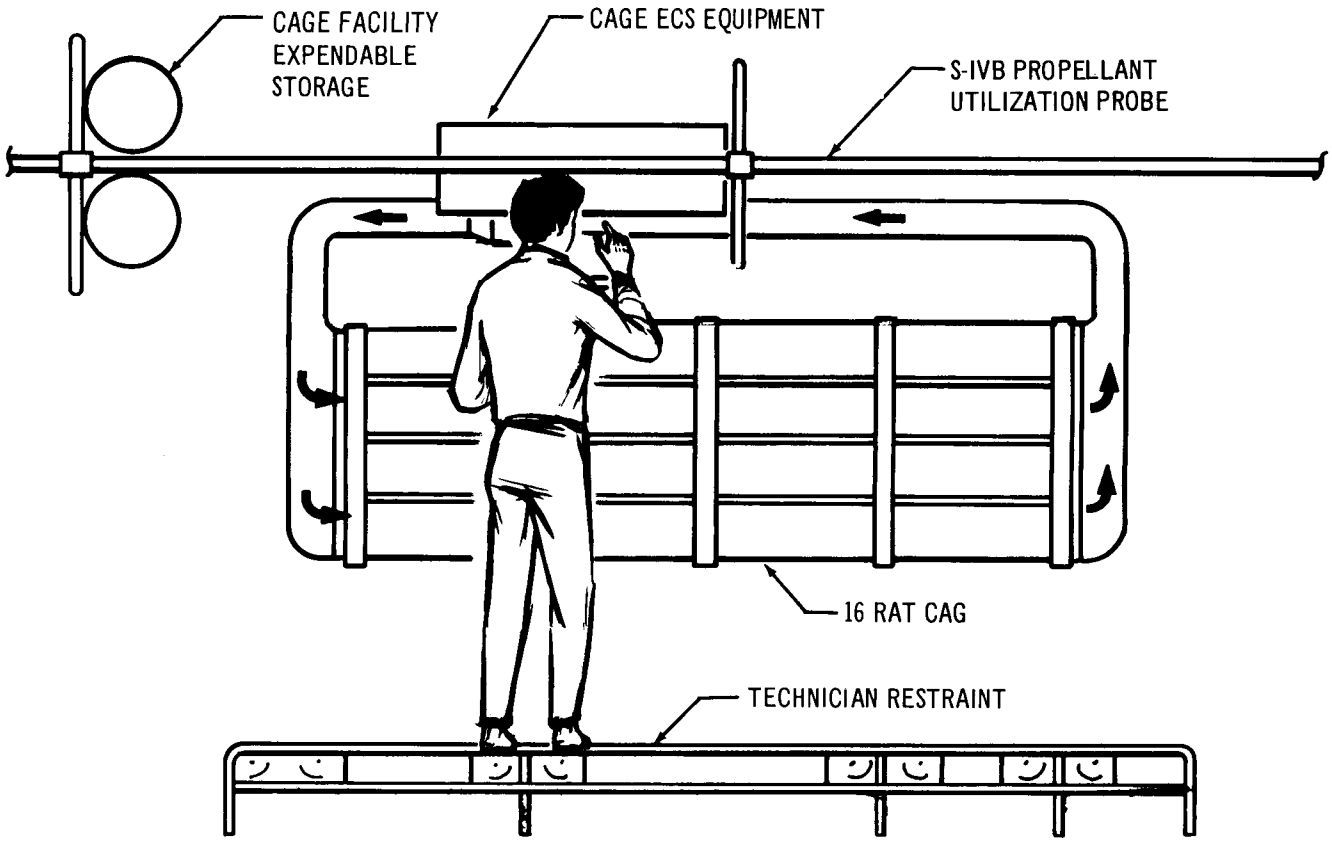


Figure 7-3. Prototype Animal Housing Facility

7.3.1.3 Rat Activity Module

The rat activity module is a multiple-purpose unit. It serves as a launch cage for a workshop-type mission. In a space-station cage facility it serves as a feeding unit, as an exercise device, and as a device for measuring biological functional parameters such as temperature, respiratory rate, and heart rate.

A rat activity module concept is shown in Figure 7-4. The concept presented is sized to accommodate a 250-gram rat. The module is composed of a clear plastic mounting panel, a wire cage, a treadmill, control levers, feeding devices, and control instrumentation. When exercise is not required, the treadmill would be replaced by a resilient surface; the feeding devices, back-restraint, instrumentation, and all other essential features would be retained.

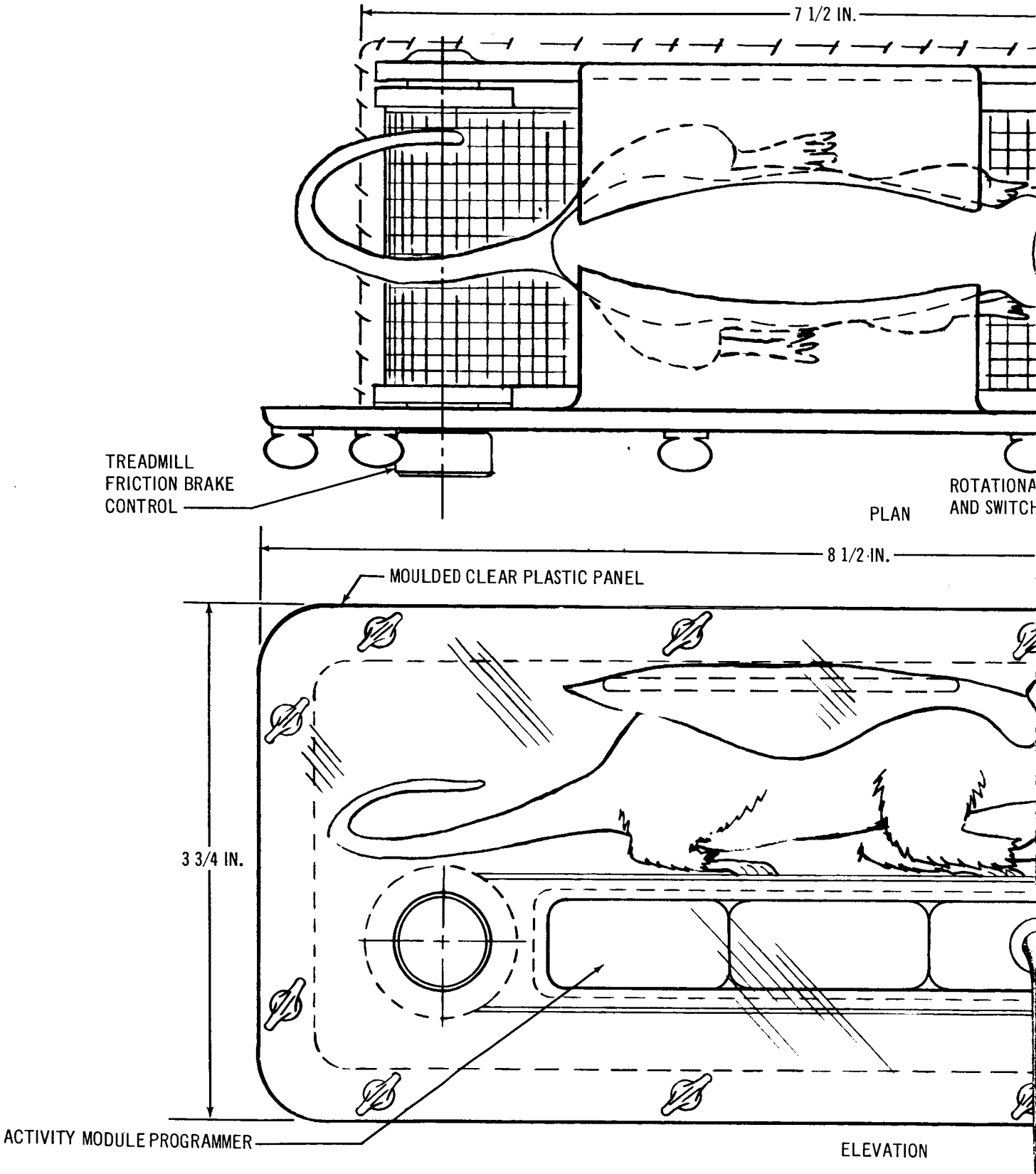
The module would be constructed generally of materials having the following properties:

1. Low outgassing rates.
2. Nontoxic outgassing material.
3. Corrosion resistance in the presence of urine, feces, moisture, oxygen, bacteria, etc.
4. Abrasion resistance and "gnaw" resistance in the case of rats.
5. High strength-to-weight ratio.

The treadmill belt could have a square, ribbed, patterned surface for traction, be flexible enough to turn around the end spools with little effort, be dimensionally stable, and chemically inert. It might be fabricated of silicone rubber.

The module front surface or panel would be transparent, rigid, have high tensile strength, and have a good dielectric strength.

The treadmill brake would be integral with one spool and be a combination solenoid brake and adjustable friction brake. When energized, the solenoid brake would lock the treadmill. When not locked, the treadmill running friction would be governed by the setting of the friction brake. An essential requirement of the friction brake is that its friction setting be calibrated and remain constant during treadmill operation.



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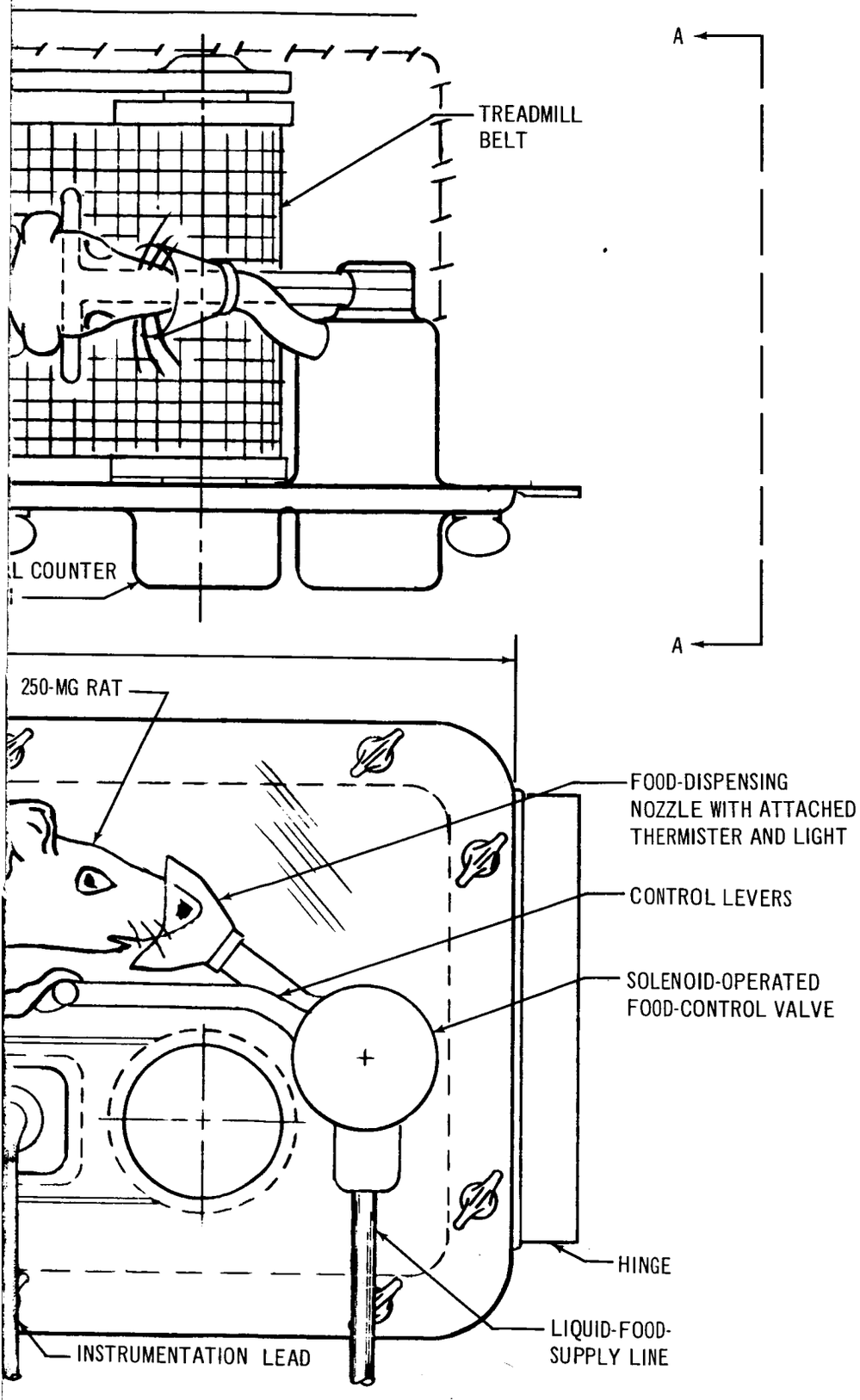

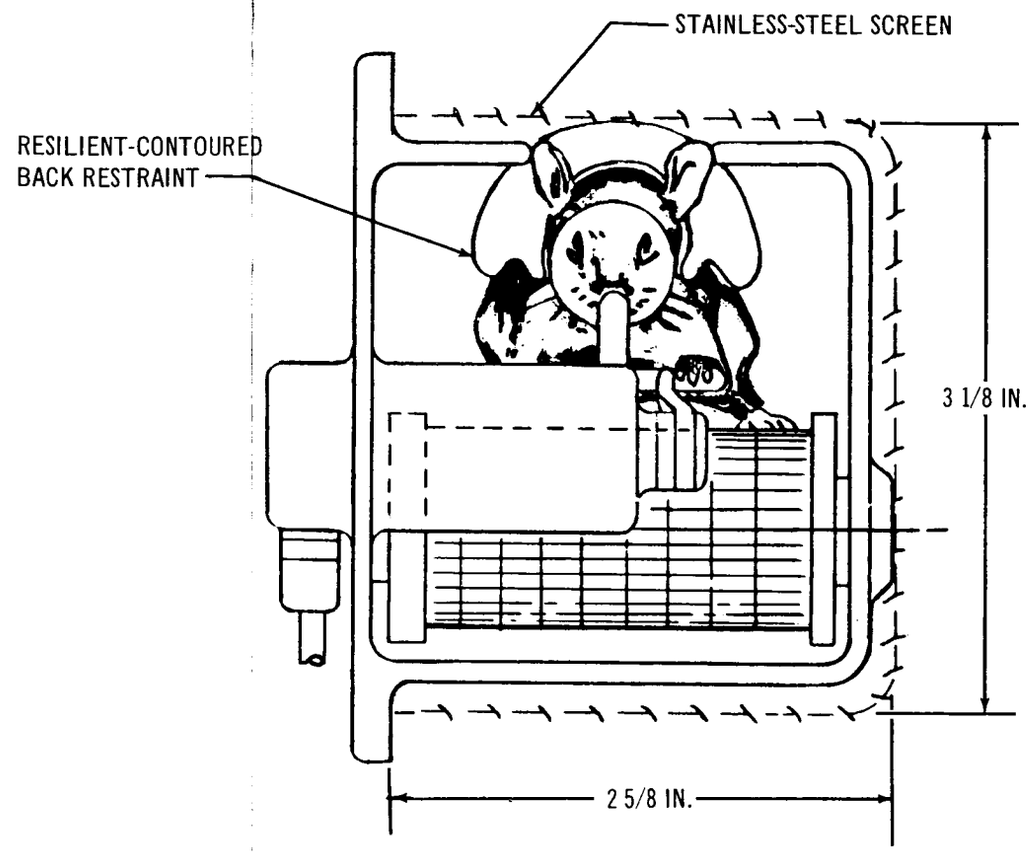

ELEVATION A-A

Figure 7-4. Rat Activity Module

The treadmill spool at the opposite end of the belt from the brake would house a rotary switch. The switch would pulse a treadmill programmer, providing a means of counting and controlling the duration of treadmill operating cycles.

The food control valve is a combination valve and lever-operated switch device. Its switch function is rat-controlled and when operated starts the biological measurement and feeding cycle. Each switch-operating lever handle has an embedded electrode, which, when grasped by the rat's two front feet, provide an electrical circuit through its chest. Upon depression of the two levers, this circuit provides a means of taking an EKG reading. Depression of the levers also starts a programmed cycle during which the rat's temperature and respiratory rate are measured and food is dispensed into a nozzle. The food-dispensing valve would be sealed to prevent food contamination by material in the cage.

The food-dispensing nozzle is shaped to contain a "squirt" of semi-liquid food, giving the rat a surface from which to lick it. Miniature lights mounted on each side of the dispensing nozzle alert the rat at the start of a feeding cycle. A thermistor embedded in the end of the nozzle food dispensing tube is used to measure the rats temperature.

A back restraint is required for operation of the treadmill in the absence of gravity. Its presence would, however, not hinder treadmill performance in a gravitational field. It would need to be designed carefully to properly support the back, but not hinder leg movement, while the rat runs on the treadmill. The back restraint must be compatible with a range of rat sizes, be gnaw-proof, and be resilient. It might be molded of a rigid plastic and padded with polyurethane foam.

The module would typically be mounted in a larger cage. A fastener system must be devised for this purpose which will provide and maintain a good seal between the cage and the module and be simple to operate. The module could serve as a cage door and as such have a flexible plastic hinge at one end. The hinge could be attached to the cage with pressure-sensitive adhesive.

7.3.1.4 Animal Activities Programmer

The successful operation of the rat activities module, described in Section 7.3.1.3, depends upon the ability of the rat to be trained to react to the signals provided by the programmer. The basic purpose of the programmer is to put each rat through an exercise, measurement, and feeding routine. The signals to accomplish this are provided consecutively to the animals. The programmer consists of a central unit which manages the daily routine for individual units in each "cage."

The functional requirements imposed on the programmer were as follows:

1. Provide exercise start signal.
2. Release the treadmill from its "locked" mode.
3. Count the number of treadmill revolutions.
4. Limit the time in which a preset (and adjustable) number of treadmill revolutions may be accomplished.
5. Provide a feeding signal and lock the treadmill at the completion of the exercise.
6. Limit the time between the feeding signal and the pressing of the EKG bar.
7. Require the EKG bar to be pressed for a minimum length of time before food is delivered.
8. Enable the delivery of a predetermined amount of food.
9. Recycle the routine to the cage if any of the constraints in Items 4, 6, and 7 are not met.
10. Provide a visual "flag" to the attendant if an animal does not complete its second attempt, and identify the animal.

The programmer system designed meets all of these requirements. In addition, it accomplishes the following:

1. Measurement signal-conditioning in the individual "cage" units.
2. Activates a data recorder during the measurement period of each animal.
3. Provides date and time code, and animal number to the recorder.

The circuits designed are suitable for integrated circuit techniques. Functional diagrams of the central and individual units are shown in Figures 7-5 and 7-6. Circuit operation is described in the following paragraphs.

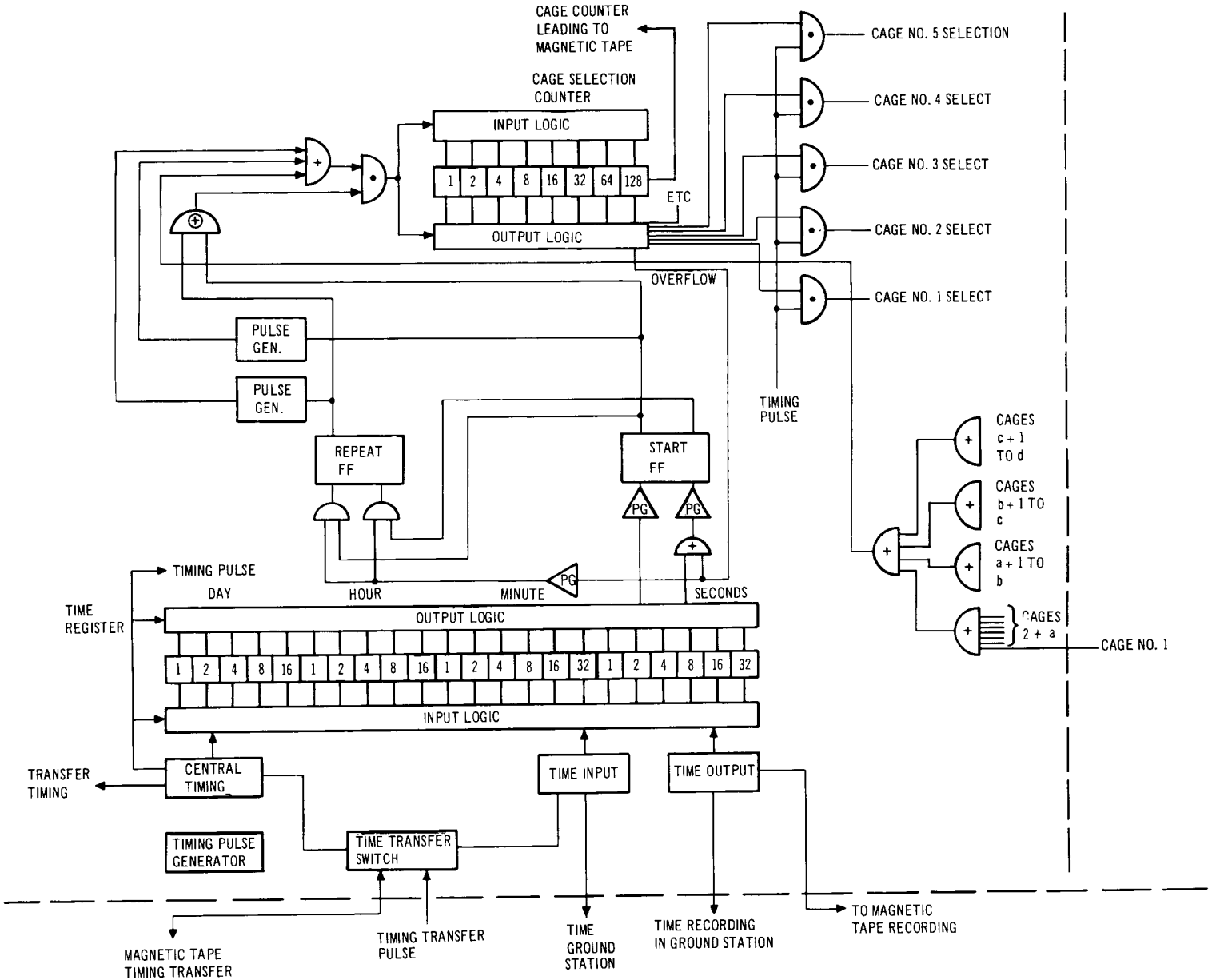

Figure 7-5. Master Programmer for Rat Activity Modules

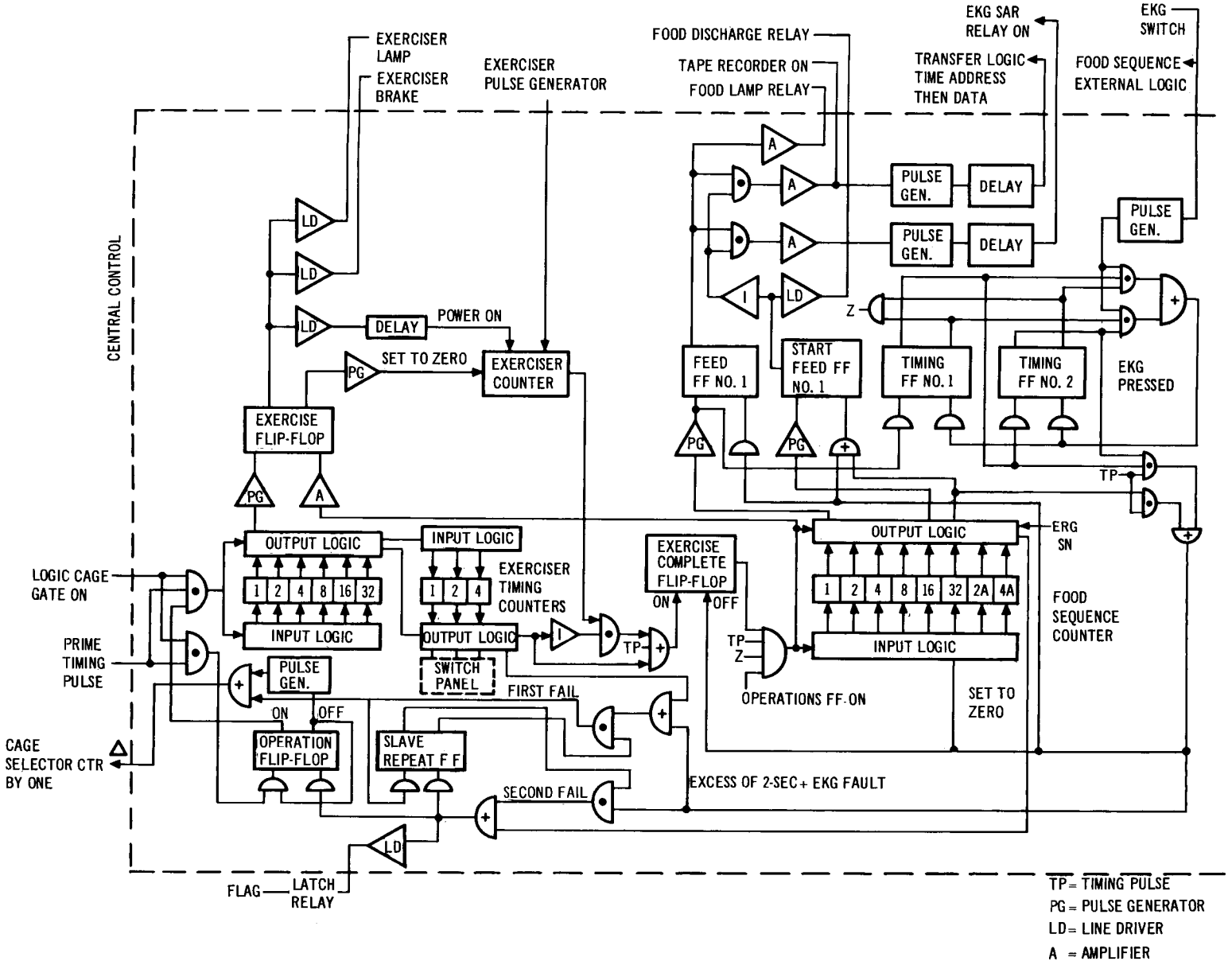

Figure 7-6. Individual Programmer for Rat Activity Modules

As the specific cage is selected, the input logic of that cage is activated and the sequence of events is started. The first pulse sets the operation flip-flop on, thereby gating on the cage electronics. The first timing pulse sets the exercise timing counter to one, thereby setting the exerciser flip-flop to one with the following sequence:

1. The exerciser lamp is turned on.
2. The exerciser brake is released.
3. The exerciser counter power is turned on.

The exerciser timing counter is incremented at 1-sec intervals by the prime timing pulse from the central control system. The animal is now assigned the task of activating a revolving treadmill a specific number of revolutions within a given time interval. The specific time interval is prescribed by the use of a switch panel on the side of each cage together with the exerciser-timing-counter output logic. The maximum exercise period allowed by present circuit designs is 8 min. If the animal subject completes the prescribed number of revolutions within the specified time interval the following events occur:

1. The exerciser lamp is turned off.
2. The food lamp is turned on.
3. The exerciser brake is activated.
4. The exerciser counter is set to zero and then the exerciser counter power is turned off.
5. The tape recorder is turned on with time and cage number placed on the magnetic tape followed by data.
6. The EKG bar is activated with no data output until the animal takes hold of the EKG bar within the 2-sec period following the lighting of the food lamp.

If, for some reason, the animal does not complete the prescribed number of revolutions on the exerciser within the prescribed period of time, the sequence is terminated and the entire exercise and measurement sequence required to obtain the food is reset for a second try at the completion of the programs in other cages.

As the food lamp turns on, the animal has 2 sec to take hold of the EKG bar, and take the feeding nozzle in its mouth. In addition the EKG bar must be closed and held for a period of approximately 5 sec, during which time the

tape recorder will record the EKG, temperature, and respiration rate measurements of the specimen. If the 2 sec period is exceeded, or the EKG bar is pressed but not held for the prescribed 5 sec of the 6- to 8-sec time period allowed the following events occur:

1. The start feed flip-flop is not turned on.
2. The food is not discharged.
3. The food lamp is turned off.
4. The magnetic tape recording is deactivated and the magnetic tape is stopped.
5. The entire animal programming of the cage is set for a second cycle at a later time and the next cage is selected.

If the animal completes the prescribed exercise within the designated time interval after the exercise lamp is turned on, the EKG bar is pressed within 2 sec after the food lamp is turned on and held for a 5-sec interval, the food discharge is performed, and the tape recorder is turned off. The food discharge is gated on by setting the start flip-flop to one. Setting the start flip-flop to one in turn turns off the tape recorder electronics and tape recorder, with the food lamp remaining on until the food-discharge cycle is completed. As the food-discharge cycle is completed, the operations flip-flop is turned off, indicating a successful feed operation of that specimen and gating off any second feed cycle.

If any fault occurs on the part of the animal to complete the feed cycle during the two opportunities presented to him, a latch relay on the cage of the animal is set and a flag of some type is displayed to indicate to the astronaut that the animal has not been fed because of some faulty conditions on the part of the animal. Each cage has its own electronics/animal programming module.

The central control system consists of a time register (for the designation of feed start time and time of the measurement readout of each animal), the cage selection counter (to select the single cage to be programmed for feeding), the logic entity (to increment the cage selection counter by one with an output of the selected cage because the feed sequence is complete or because of a fault condition occurrence pulse), and the output logic (to gate on the one and only cage to be sequenced for exercise and food). The setting up of time in the

time register is from the GSE time unit with a readout of the time register to GSE provided to ensure correct transferral of time to the animal programmer.

The holding and encoding of time and cage number in the magnetic tape unit is assumed to be a part of the magnetic tape unit and not a part of the animal programmer. A modest effort was made to optimize the circuitry but final circuit designs will make some changes to their preliminary design effort. Every effort has been made to design a system easily adapted to the use of microminiaturization.

In the event of a failure to exercise the prescribed amount, no recorded data are provided. If the animal fails to hold the EKG bar for the full 5 sec (out of 8 sec), data will be recorded during this time but the animal will not be fed on that cycle.

It is possible, with a feedback wire from the nose-temperature transducer signal, to permit the discharge of food to the animal only when the animal has its mouth over the food-discharge outlet.

7.3.2 Equipment Experiment Data Requirements

Three types of data will be required to evaluate the equipment being tested: measurements, visual (television or photographic), and astronaut comments. There will not be a need for real-time data. All measurement and television data and astronauts' comments may be recorded in the workshop data system and "dumped" in the normal routine. If facilities for recorded television are not available, motion picture coverage will be necessary. This would limit the amount of visual data available for later analysis. The following is a list of the data required in each of the three categories.

1. Measurements.
   - A. Animal-housing total pressure.
   - B. Animal-housing partial oxygen pressure.
   - C. Animal-housing partial carbon dioxide pressure (input and output).
   - D. Animal-housing temperature (input and output).
   - E. Animal-housing gas-flow rate.
   - F. Animal-housing gas humidity (input and output).

G. Animal-housing oxygen-supply pressure.

H. Animal-housing nitrogen-supply pressure.

I. Animal EKG.

J. Animal respiration rate.

K. Animal oral temperature.

2. Visual Data.

A. Opening of animal launch capsule.

B. Installation of rat activity modules.

C. Completed EC/LS and housing installation.

D. Animals during programmed activities.

E. Animals during casual periods.

F. Urine and feces drift to the filter.

G. Other subjects considered by the astronauts to be worthy of recording.

3. Comments--This type of data will depend entirely on the astronauts. It should include comments on such items as equipment failures, assembly problems, animal behavior, and constructive suggestions concerning any of these. These comments will be most effective if recorded at the time of the observation, particularly together with visual recordings, rather than being recorded or written at a later time.

7.3.3 Equipment Experiment Support Requirements

The weight of the total experiment package at launch will be 245 lb. The volume of the equipment in its stored condition is 10 cu ft. It will occupy a volume envelope of 11 cu ft when installed in the workshop.

Electrical power requirements consist of 10 W continuous load for the circulating fan, 20 W intermittently for data acquisition and 10 W for 2 hours, twice a day, for the rat activity module.

Because the experiment will include a closed-loop environmental control system, no requirement will be imposed upon the workshop resources in this area.

7.4 PHYSIOLOGY EXPERIMENT

It has been pointed out previously in this report that the use of animals in equipment-development experiments in orbit presents an opportunity to conduct physiology experiments. Such an experiment is described in this section.

While the prime purpose of describing the experiment is to illustrate the nature and scope of the potential experiments, it is nevertheless considered a suitable candidate.

7.4.1 Physiology Experiment Objectives

Deconditioning due to weightlessness during prolonged space missions may be a serious limiting factor to man's exploration of space. More data need to be accumulated to determine the effect of exercise as a protective measure.

Small animals such as laboratory albino rats permit light weight- and power-requirements and low-cost investigation. Large amounts of baseline data exist on laboratory animals. Although it is appreciated that direct extrapolation of data from rat to man is not possible, information obtained from rats can permit inferences about mechanism involved, and data obtained can be used to establish guidelines about relative zero-g effects on man.

Progressive deconditioning during bed rest causes a decrease in red blood-cell production. Normal physical activity under 1-g creates a continuous destruction of red blood cells. The bone marrow and blood-forming organs respond by producing on a regular basis the amount of red blood cells that are destroyed. Under weightlessness and bed rest, decreased physical activity results in decreased red blood-cell production manifested by decreased red blood-cell mass and a relatively inactive bone marrow. Physical activity after prolonged deconditioning may result in acute destruction of red blood cells, reduction in blood volume, and the release of immature red blood cells. Decreased orthostatic tolerance occurs.

Cardiovascular deconditioning causes a decreased exercise tolerance manifested by a marked increase in heart and respiratory rate with an overall decrease in the amount of work that can be performed. An increased storage of catecholamine products in the myocardial cells impairs the heart's ability to efficiently use oxygen and causes a predisposition to myocardium irritability and cardiac arrythmia. Muscle mass and tone are decreased with increased calcium mobilization and excretion of calcium in the feces and urine. Bones become demineralized. Calcium, phosphorus, and nitrogen imbalances occur. The response of the cardiovascular system to a quantified

workload is an index of the general physical condition. The rate of the return of the respiration and cardiac rate to pre-existing levels and/or the attainment of a "steady state" can be utilized to determine deconditioning or reconditioning during exposure to long-term weightlessness.

Therefore, it is suggested that rats be used as typical experimental subjects not only to validate the animal EC/LS system design, but also to provide useful data concerning deconditioning and reconditioning under weightlessness conditions.

The objectives of this experiment are (1) to determine the effects of exercising at no work load, and at minimum and maximum work loads during a weightless state; (2) to determine whether exercising can prevent cardiovascular deconditioning, decreased skeletal tone and skeletal demineralization; and (3) to validate the EC/LS design.

7.4.2 Physiology Experiment Procedure--Preflight

One hundred 200-gram male Sprague-Dawley or Wistar strain rats will be chosen at random from an inbred colony. Each rat will be placed in an individual feeding monitoring unit and will be taught to obtain food by the Skinner box technique previously described. Detailed histories will be kept on each rat. They will be housed, trained, and monitored until 3 days before launch. At that time, four groups of 16 animals each will be randomly selected from those animals which have attained a body weight of 250 grams. To ensure that diet does not affect mineral and nitrogen balance, the animals will all be kept on the same diet as will be used during the flight conditions.

These 250-gram rats will be weighed, measured, and examined to ensure the healthy condition of each animal. Urine and fecal samples will be obtained and analyzed for Na, Ca, K, chlorides, and protein. A venous blood sample will be taken from the tail vein or via cardiac puncture and, by micro-analysis techniques, will be assayed for catecholamines (epinephrine and norepinephrine) and 17-hydroxy corticosteroids. Sections of the talus, os calcis, capitate, and hand phalanges will be evaluated for skeletal mineralization by radiographic densitometry techniques as utilized in medical studies in Gemini 7 flights. Bone ash studies will also be done on returned skeletal specimens.

Each group of 16 animals will be packaged in individual feeding monitoring units under identical conditions in transfer modules. Each 16 rats will be divided into four subgroups of four as follows: (1) Subgroup I--treadmills will be set so the rats will have to expend a maximum work load (friction of 15 grams) to receive a food reward; (2) Subgroup II--treadmill will set at a minimum work load (friction of 5 grams); and (3) Subgroup III--treadmill will be set to run freely at no work load. These three subgroups will be arranged in the area closest to the "air intake" end of the biomodule and will be arranged according to Figure 7-4. Subgroup IV will be divided into the following: two animals with the treadmill set at no load, one animal with treadmill at maximum work load, and one animal at minimum work load. Subgroup IV will occupy the cross-sectional area most distal to the air intake end of the module. (Therefore, this subgroup will be subjected to the air flow which has passed through three preceding filters.)

When the rats are later transferred into the S-IVB workshop, they will be kept in the same relative positions of air flow.

Four transfer modules will be prepared with 16 rats each. Two transfer modules will be utilized as ground controls, one will be installed on-board the S-IVB, and one will be kept at the launching site as a standby. Should only one module be used for flight, there will be three ground control modules. Each flight experimental animal will act as his own control and will be compared with similar ground controls.

7.4.3 Physiology Experiment Procedure--Flight

The rats will be monitored by a tape recorder activated before launch, during launch, and until preparation of the S-IVB workshop area (EKG, respiration rate, food intake, and exercise data). When the workshop area has been prepared, the individual feeding monitoring units will be removed from the transfer module and installed as part of the living cages. Monitoring units again will be activated. Filters in the monitoring feeding units will be removed inside plastic bags and quick frozen for later study. Periodically filters will also be removed from the cages when the animals are installed in the S-IVB workshop. These filters will be quick-frozen, returned to an Earth laboratory, leached and analyzed for urinary and fecal minerals, bacterial flora, and

possibly for protein substances. Standard laboratory chemical and bacterial analysis techniques will be used. Qualitative and possible quantitative determinations can be made which will give a gross comparison with bone demineralization and intestinal flora data.

This initial experiment has been designed to require a minimum of the astronaut's time. Once each day one crew member will check the animals condition by visual inspection. Periodic documentation of animal-man-equipment interrelationships will be accomplished by polaroid photographs. Polaroid photographs will be taken as required of the animals, photographing through a grid at a set distance to document body size and proportions. Should any animals have expired, they will be removed in a plastic bag and stored in a quick-freeze storage unit. The cage will be cleaned with a sponge wet with mild detergent and the filter will be replaced with a clean one. (These sponges will be immersed in fluid and sealed in plastic before flight.)

Once every 7 days, all filters will be replaced. Old filters will be removed in plastic bags, sealed, and quick-frozen for later Earth analysis. At the end of the experiment, the astronaut will utilize a plastic bag as a glove box, 2 mm of blood will be drawn from the tail vein or by cardiac puncture from each animal. Vascuosyringes will be used. These samples will be frozen and stored for Earth analysis. Then each rat will be placed in a plastic bag and sacrificed by use of a blunt blow over the sixth cervical vertebra area and quick-frozen. If possible, representative live animals will be returned for comparison with ground control animals. The transfer module will be reactivated as a housing and transport unit for the returned animals. Bone densitometry studies will be made on the returned preserved and live experimental animals and compared with ground controls.

7.4.4 Physiology Experiment--Expected Results

Some rats will adjust to an exercise work load and their heart and respiration rate will reach a steady state. Rats not exercised may become deconditioned, and cardiovascular and respiratory rates may become inadequate and variable. Should any of the rats become deconditioned because of weightlessness, bone demineralization will occur, and urinary and fecal calcium will be excreted. Catecholamines can be excreted also.

7.4.5 Physiology Experiment--Analysis of Results

In-flight recordings of EKG, respiratory rate, body temperature, exercise, feeding data, and photographs will be compared with ground-controls. Each subgroup will be compared. Venous blood samples will be analyzed for catecholamines and 17-hydroxy corticosteriods. Quick-frozen speciments will be compared with ground-control specimens sacrificed and frozen at the same time. Representative animals will be sacrificed, quick-frozen and returned for histological-pathological analysis. Also, live animals will be returned if possible for analysis. Special attention will be given to organ weights (for example, liver). Bacterial cultures of the intestinal flora will be done. Because a fairly large difference in final body weight may exist between the rats being subjected to various exercises and because comparisons of absolute organ weights are difficult as organ size is related to body size, the techniques of Heroux and Gridgeman (Reference 7) will be utilized. They emphasized that differences in body weights of rats should be compensated for by using the regression coefficients of organ weights to body weights (obtained by the least square method) to calculate organ weights for all animals on the basis of a common body weight.

It is expected that analysis of regressed organ weights will show that rats undergoing minimal, moderate, and heavy exercise will have heavier adrenals and a normal or slightly larger heart size than "normal" preflight animals. Bone densitometry determination will be made.

Fischer's factorial techniques will be used for data that are appropriate. Such techniques will provide analysis of two or more independent variables occurring simultaneously. Much of the data, because of the nature of the experiment, will not be applicable to statistical analysis, and will be presented in graphic form.

7.5 EXPERIMENT PROGRAM PLANS

The most important factor to be considered in preparing a schedule for the development of this experiment will be the workshop mission to which it is assigned. If a near-term flight is available (early 1969), then the detailed

design and fabrication program must begin in 1967. Choice of a later mission would permit an analysis and review of detailed design before proceeding with fabrication and tests. The selection of a biology experiment to be performed with the equipment experiment must be done in the early months of the program to permit the incorporation of its special requirements in the equipment design.

Section 8
RECOMMENDATIONS

In this report, the results of the various aspects studied may be considered as subtle recommendations; however, a clear statement of these recommendations will be useful to the NASA in formulating its future program plans. From study contracts related to the S-IVB workshop and other space stations which Douglas is conducting, the Company is aware of many details concerning these programs which will constrain or enable animal research activities. It is fitting, therefore, that Douglas present its recommendations as a result of its consideration of the relationship between the space station programs and the animal research requirements.

8.1 PROGRAM JUSTIFICATIONS

In Section 1 of this report, reference was made to an official document which provides justification for animal research programs in space (Reference 1.) This section will not presume to provide further justification for these programs; rather, it will provide a rationale to support the approach recommended for achieving the programs.

The experiment program described in Section 2 of this report is based upon the need for information concerning the effect of the space environment, specifically zero g, on the physiological subsystems of man. It was further pointed out that information obtained from animal studies is required to illuminate this area of investigation. This fact was also mentioned in the documents referred to above. The varying nature of the techniques to be used in conducting experiment programs which will lead to this information requires a well equipped laboratory in space, equipped to permit an experimenter to observe the results of his experiments while in space, rather than relying solely on examination and reduction of data on Earth. To provide such a laboratory will require new techniques and equipment suitable for operation in the space environment. It is essential, therefore, that such

techniques and equipment be developed before the final design of the operational space station animal research laboratory.

The urgent need to obtain the mission-oriented data is justification enough for developing a laboratory for a space station complex. The need to conduct experiments which are not mission-oriented, such as, bioscience type experiments, has been recognized and the facility must therefore also provide for this type of experiment program.

The nature of the tasks associated with these experiment programs is such that a highly trained physiologist will be required in the crew of the space station. Although much of the work may be automated, the observations and interpretation of the data will require the competence of a specialist. The presence of a trained assistant and/or backup experimenter is also necessary.

8.2 PROGRAM CONTENT

As Douglas sees it, the program which will lead to an operational laboratory in space, that is, one in which the emphasis is on biological research and not equipment development, consists of three parts:

1. Experiment selection and design.
2. Supporting research and technology development.
3. Space station laboratory design.

If advantage is to be taken of the facilities expected to be available in the early 1970's, it is essential that the life sciences community begin definition of the experiment program to be conducted in the laboratory and the design of the individual experiments selected. From knowledge of the biological data obtained to date and the specific data required, it appears practical to begin the definition of the space laboratory program. Time is still available to permit some flexibility in the program but, after 1968, it will be necessary to have a firm program to permit the detailed design of the laboratory.

While it is an accepted fact that a well equipped laboratory will permit the performance of a wide range of experiments, it has been the Company's experience that the lack of detailed information concerning experiment

hardware and support requirements is a major stumbling block in the conceptual design of space station configurations. Clearly, before the detailed design of a space station laboratory is undertaken, it must be known whether the design is for a large rodent population, a large primate population, or a variety of animals.

The supporting research and technology portion of the program will develop the equipment and techniques necessary for the operation of the space laboratory. This study has identified many SRT items of a general nature. The experiment program discussed above will identify more SRT items required for the laboratory. A successful SRT program will permit the laboratory to concentrate on animal research experiments rather than on equipment experiments.

The design of the space laboratory should begin as soon as possible so that its requirements will be identified to the space station program office. There will be severe competition for the resources available in the space station. The approach might be taken of accepting whatever space and other facilities are benevolently made available to the research program, and fitting the experiment program into those facilities; however, a more aggressive approach with a firm statement of requirements is necessary if the animal research program is to receive proper recognition. Several problems associated with an animal research facility (for example, isolation for contamination control, isolation for zero-g requirements, the use of a semi-dependent module, and so forth) must be resolved before detailed design can take place. If the required SRT cannot be accomplished prior to the first ground-equipped early orbital space station (EOSS), then it will be necessary to continue the development of equipment and techniques in that mission. The resources available in EOSS will permit a sizeable animal resource program coupled with the SRT program. The information gathered on this mission will then lead to the design of, and experiment program for, a laboratory on the long-term space station in the 1975 period.

8.3 UTILIZATION OF SATURN WORKSHOP MISSIONS

Douglas is currently conducting for the NASA (MSFC) an extensive study of the applications and configurations of the Saturn S-IVB Workshop concept

(S-IVB Station Module Study, NAS8-21064). The information available from this study permits us to make confident recommendations with respect to the utilization of such missions in the animal research facility program. The most important fact is that workshop missions will be severely payload limited. In this study, we have investigated the capability of such a mission to provide facilities required to perform rather elaborate animal experiments in space. One of the results of the study presented in Section 4 indicates that if the entire mission can be devoted to the animal research program, then such a program could be conducted; however, the reality of the situation is that none of these missions will be exclusively devoted to a single discipline, and will be shared by many areas of interest. It is therefore clear that the full-scale programs described in this report will not be possible. Furthermore, the amount of SRT activity which must take place before an animal research program can be conducted on an operational basis precludes the conduct of such a program in the time frame in which workshop missions will be available. The conclusion, therefore, is that operational animal research programs will be impractical in workshop type missions.

The S-IVB workshop missions do provide an excellent opportunity to conduct the SRT activities which have been identified in this report and will be identified in subsequent studies. Typical of this type of work is the equipment experiment described in Section 7 of this report. The time required to conduct the experiment and the skills required of the experimenter are well within the capabilities of the S-IVB Workshop Mission. Furthermore, this type of experiment does not impose a strain on the resources of the workshop and therefore would meet with acceptance by the experiment review board. Similar experiments designed to develop equipment and techniques could be programmed on subsequent workshop missions leading eventually to the availability of operational hardware for a space station laboratory. It is recommended, therefore, that a concentrated effort be made to utilize the workshop missions for the SRT program. As in the experiment described in Section 7 of this report, animals no doubt will be required to test the design effectiveness of the equipment or techniques. The presence of these animals in the zero-g environment provides an opportunity to conduct secondary physiology experiments during the SRT program.

8.4 PROGRAM PLAN

From knowledge of the requirements for the animal research program, and our awareness of the availability of space facilities and the probable schedule by which these facilities will become available, it is recommended that the program for an animal research facility be conducted in the manner outlined in this paragraph. Figure 8-1 shows the relationship between the recommended animal research facility program and the Saturn workshop and EOSS programs. The launch dates shown were supplied by NASA to Douglas for use in the S-IVB Station Module Study. There is some possibility that workshop missions similar to either Cluster 1 or AWS-LO-B may be flown after the LO-B mission and prior to EOSS No. 1. The EOSS development program shown is recommended by Douglas as a result of that study. The possibility of subsequent EOSS missions (No. 2 and No. 3) is speculative, but they have been included to show practical separation times if they are required.

It is important to note that experiment equipment must be ready for integration 1 year before the launch date.

The animal research facility program elements are those that were recommended in Section 8.2 The experiment portion has been separated into three elements. The major constraint upon the program is the necessity of providing detailed support requirements to the EOSS design phase in early 1969. As pointed out in Section 8.2, this laboratory may combine an animal research program with an SRT program.

The vertical arrows show the main requirements for information or hardware transfer; dotted lines after these arrows indicate the need for continuing coordination.

SRT projects must begin in 1967 if development experiments are to be ready for the Cluster 1 mission. Experiment assignments already made for this mission may preclude approval of additional ones, and a later mission (for example, AWS-LO-B) will be the goal. The magnitude of the required SRT, both on Earth and in space, is such that an early start of a continuing effort is required.

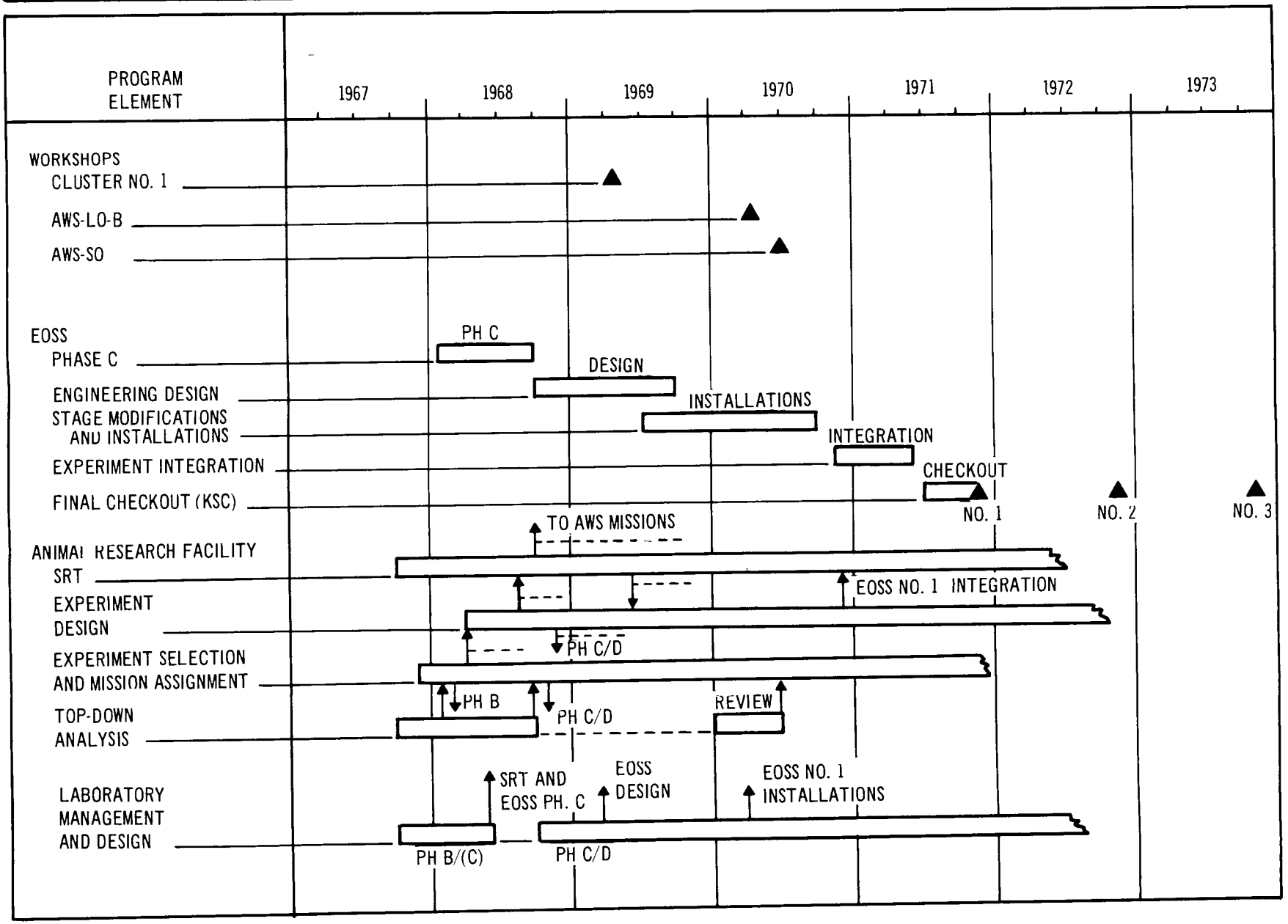

Figure 8-1. Animal Research Facility Program and Related Schedules

Before experiment design and experiment selection can take place, a top down Analysis of life sciences in space should be started. This latter effort will provide confidence in the experiment program. As pointed out previously in this section, sufficient awareness of information requirements exists to permit a start on experiment selection and the initiation of experiment design. The results of the top-down analysis will expand the experiment lists but are not expected to modify the initial experiment effort. It is suggested that a thorough review of the analysis be conducted at a later time to consider information which will become available after early AAP or Apollo flights.

Appendix
ANIMAL RESEARCH FACILITY STUDY STATEMENT OF WORK

Douglas Aircraft Company will furnish the necessary facilities and personnel to accomplish the following tasks.

A. 1 PREPARATION OF EXPERIMENT LISTS

Douglas will prepare a complete list of long-term animal experiments considered feasible and desirable in an Earth-orbital SRT facility adapted from the S-IVB launch vehicle.

A. 2 DEFINITION OF EXPERIMENT GROUPS

A selection and detailed description of three typical experiment groupings will be prepared to be used respectively in the following design concepts:

1. The spent S-IVB of a Saturn IB.
2. The prelaunch modified S-IVB of a two-stage-to-orbit Saturn V, using both the hydrogen and oxygen tanks for animals and crew.
3. The prelaunch modified S-IVB of a two-stage-to-orbit Saturn V, using only the oxygen tank for animals.

A. 3 DEFINITION OF EXPERIMENT SUBJECTS, APPARATUS, AND SUPPORT REQUIREMENTS

Applicability of various animal subjects will be studied. Douglas will prepare a materials/equipment requirement matrix for each typical experiment grouping. Three requirements will be prepared for each of the experiment groups identified in Task A. 2.

A. 4 ANALYSIS AND DEFINITION OF EFFECTIVE MISSION PROFILES

On the basis of mission objectives and experiment programs, suitable and effective mission profiles will be analyzed and described. The analysis will consider the following:

1. Facility weights.
2. Launch stage requirements.

3. Total facility vehicle configurations.
4. Orbits to be attained.
5. Orbit stay times.

This analysis will be conducted for each of three facility design concepts. Douglas will prepare a time-line analysis and description of necessary crew performance as a function of mission profile, operational requirements, and experiment activities required.

A. 5 DESCRIPTION OF VEHICLE CONFIGURATIONS TO SUPPORT MISSION PROFILES

Preliminary layout drawings will be prepared showing the method by which the S-IVB may be adapted to satisfy the total mission requirements of the three design concepts of Task A. 2.

A. 6 DESCRIPTION OF VEHICLE MODIFICATIONS AND ADDITIONS REQUIRED

A list of S-IVB modifications required by the three design concepts will be prepared. A description of each change will be included. The supporting subsystem changes and additions will be described. Preliminary performance requirements for these subsystems will be prepared.

A. 7 ANALYSIS OF CREW ACTIVITIES

The housekeeping and experimenter activities of the crew will be identified and studied. Time-line analysis of these tasks will be prepared.

A. 8 PREPARATION OF A STATEMENT OF WORK FOR THE DEFINITION PHASE

Douglas will prepare an analysis and presentation of the requirements for conceptual design studies-in-depth required as a follow-on to the present SRT effort.

A. 9 IDENTIFICATION OF SUPPORTING RESEARCH AND TECHNOLOGY EFFORTS

Douglas will identify the SRT efforts required to accomplish the following:

1. The conduct of premission experiments.
2. The design and development of orbital SRT facilities required by the experiments.

A. 10 PREPARATION OF PRELIMINARY PROGRAM

Douglas will propose the preliminary program plans to accomplish the efforts defined in Task A. 9.

A. 11 STUDY DIRECTION AND STAFF

Douglas will provide a study director and staff to accomplish the program tasks defined above for a 7-month study.

A. 12 PREPARATION OF REPORTS AND TRAVEL

Douglas will prepare and submit reports and will travel within the dollar limitations stated in the cost attachment to the contractual letter of transmittal.

REFERENCES

1. The Space Program in the Post-Apollo Period. Report of the President's Science Advisory Committee (PSAC), February 1967. Page 22, Available and Needed Biomedical Information; Page 25, Recommendations; Page 38, Justification for a Space Station; Page 40, Recommendation.

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